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WP1 - DELIVERABLE

Composite Indicators measuring the progress in the construction and integration of a European Research Area

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Executive Summary

This report is the deliverable of the first work package (WP1) of the feasibility study entitled: 'ERA monitoring: Composite Indicators measuring the progress in the construction and integration of a European Research Area', financed by DG RTD. For this deliverable we developed a composite indicator to measure progress in the construction and integration of a European Research Area (ERA). The indicators required for this study and the theoretical framework have been drawn and adapted using the headline indicators proposed by the expert group report[1] on 'ERA indicators and monitoring' 2009 EUR 24171 EN. The report combines economic and statistical expertise and presents a comprehensive and flexible framework for an evidence-based monitoring of progress towards the European Research Area.

The conceptual framework is composed of three domains: the inputs towards the implementation of the ERA, which includes funding levels and policy actions for the coordination and opening-up of the funding for research; the ERA making, which intends to measure the interactions between actors in the higher education, national research and innovation systems; and the outcomes of ERA, which is meant to capture the realization of the knowledge society in terms of attractiveness and excellence of the European R&D and innovation system.

The completion of this first work package took two months, starting on May 1st, 2011. In this period considerable time was allocated to the collection and compilation of the data for the underlying indicators. The team has worked to collect the most recent and reliable data for as many countries and as many time points as possible. An extensive quality report for the data is included in this deliverable with a survey of alternative sources which update the information contained in the 'ERA indicators and monitoring' 2009 expert group report.

The ERA envisions making European research and innovation less fragmented and more competitive. For this reason the team proposed a composite indicator intended to benchmark the <u>performance of ERA Countries</u> towards the implementation of the ERA. The countries included in this analysis are all EU Member States, EFTA countries, Candidate Countries and Israel. In addition, a modified version of the composite indicator was built with the intention to compare the performance of the European research and innovation system with that of a set of benchmark countries (US, JP, CN, BR, IN, KR, RU). This modified composite indicator was called <u>international benchmark</u>. The *raison d'être* of this comparison found its roots in the context of the former Lisbon strategy and the current EU-2020 initiative. In this modified composite, two indicators about cooperation and cohesion within the ERA were excluded as these are meaningful only for European Countries.

The composite indicators were calculated for two different time points, which were named *begin Lisbon* (around year 2000) and *begin EU-2020* (as a proxy for 2010). This permitted to compare the performances of the Countries across a time interval spanning over approximately 10 years, which looked appropriate to highlight possible structural changes in the intrinsically slow process of modernization of the Research and Innovation system. The composite indicators were built using different techniques of imputation, normalization and aggregation.

As far as the international benchmark was concerned, the European Union -- as an aggregate of its 27 Member States -- definitely made some improvement in building the ERA (Figure A) over the last 10 years or so. This is remarkable, especially in light of the challenging process of enlargement that occurred during this period. Yet, South Korea and China progressed towards the implementation of their own research area at a much more rapid pace. In particular South Korea overtook both Europe and Japan at the *begin EU-2020* time point, setting itself after the leader, the United States. On the other hand, the United States showed a modest decline in performance over the last 10 years. In summary, we observe a convergence in the performance of US, South Korea and Japan, which tend to form a cluster of leading countries, followed by the EU-27, Russia and India, in decreasing order of

[1] The full report is available at: http://ec.europa.eu/research/era/pdf/era_indicators&monitoring.pdf

performance. China, with its impressive progress over the past ten years, has easily overcome Brazil and is likely to soon reach the level of India.

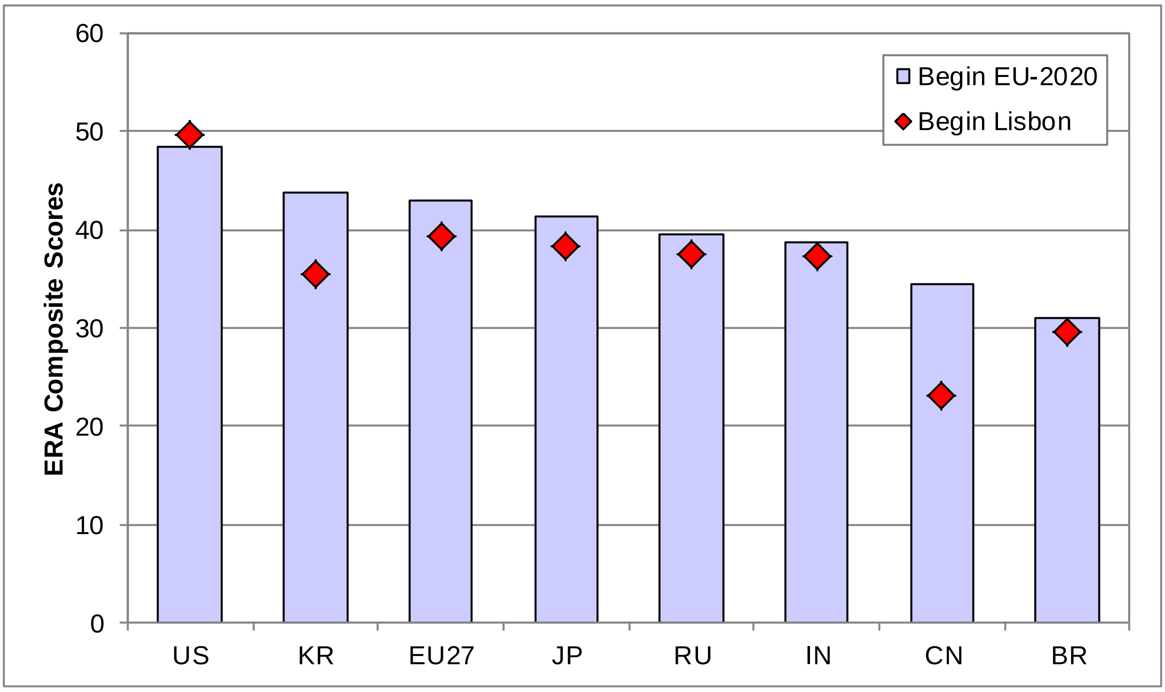

Figure A: The overall ERA composite scores for the international benchmark at two time points

Considering the performance level of ERA Countries (Figure B), the most advanced are the Scandinavian and EFTA countries, with Israel, Austria and Luxembourg. These Countries are, except Luxembourg, the biggest R&D and education spenders relative to their GDP (for Finland and Israel the business sector is a strong contributor to R&D expenditures). Luxembourg is strong in mobilising R&D to address grand challenges and hourly labour productivity. Moreover, Scandinavian, EFTA Countries and Israel demonstrate Excellence of the S&T base in terms of citations in publications and Universities. Among the drivers of ERA performance for Austria, we observed its high share of innovating companies and its success in attracting international business R&D investments.

The rest of the former North-Western EU-15 Countries follows and is above the EU27. The main drivers of the good performance of Germany and France are the consistent number of patent applications in grand societal challenges and the considerable investment in R&D and higher education. The high share of innovative firms also contributes to the above-average performance of Germany. The above-average performance of United Kingdom is explained by the consistent number of patent applications in grand societal challenges and by its leadership in attracting international business R&D investments.

All New Member States (except Cyprus) are found below the EU27, together with Spain, Greece, Portugal and Italy.
All actors (government and business) in Greece manifest very modest input to the R&D system, although this is also low in the other Mediterranean Countries. The foundations of the knowledge-based economy in Greece are the weakest among all the Countries. Portugal and Greece suffer from a very low level of R&D mobilisation to address grand challenges in absolute terms. On the other hand, the relative share of patents in grand challenges in Greece is near the EU average. The excellence of the S&T base shows a very unbalanced picture in Portugal where the quality of publications is high but the Country lacks Universities in the top 250 in Europe. Portugal shows also a paradoxical situation in which the share of innovating firms is large but the Country lacks attractiveness by foreign R&D investors. In addition to increase funding of the R&D system, Spain should also increase its level of scientific collaboration with the lowest R&D EU partners in order to improve its below average position.

R&D and education investments are quite far below the EU average for New Member States, except for Czech Republic and Slovenia which demonstrate the strongest commitment among their peers. For the New Member States the knowledge-based economy is only partially developed despite the fact that some New Member States perform well in a few dimensions. A few examples are given. Romania excels in patent specialisation in grand societal challenges; Slovakia excels in attracting R&D investments from abroad; knowledge-based sectors have a high share in Hungary; Cyprus, Poland, Estonia, Lithuania have a high share of tertiary graduated young population, which represents a strong potential for the development of the ERA.

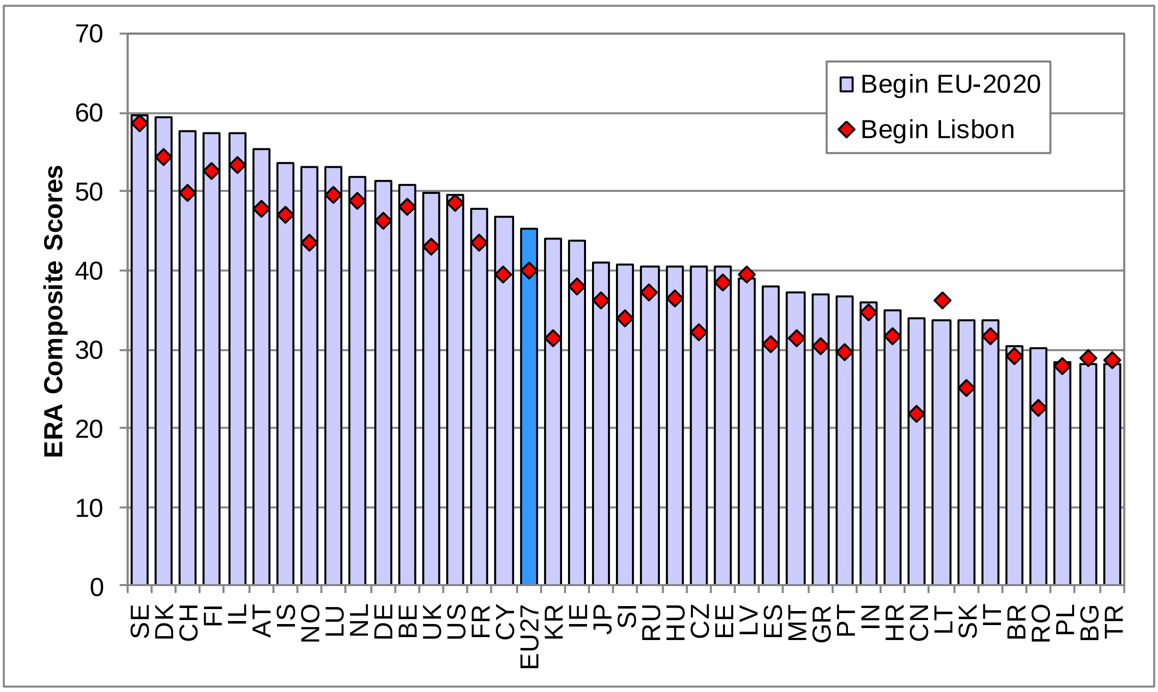

Figure B: The overall ERA composite scores for the European Countries at *begin Lisbon* and *begin EU-2020* time points.

The overall assessment of the composite indicator, carried out using uncertainty analysis, reveals that it is robust with respect to alternative assumptions used to build it, though few countries rankings exhibit too much volatility, hindering the evaluation of performance changes over time. However, the assessment reveals two particular shortcomings in the conceptual structure:

- the domains ‘inputs towards the implementation of the ERA’ and ‘outcomes of the ERA’ are coherent from a conceptual and statistical point of view but the structure of the domain ‘ERA making’ should be thoroughly revisited.
- the composite does not have a well-balanced structure, which is dominated by the domains ‘inputs’ and ‘outputs’, whereas the domain ‘ERA making’ has a weak influence on the composite scores.

The team tested the framework structure proposed by the expert group. The available data describe a very heterogeneous configuration of ERA, which can hardly be confined into three dimensions. This makes the quantification of the **‘**ERA making**’** domain quite loose and approximate. Considering also the absence of data for some indicators, the team recommends international data providers (Eurostat, OECD, UNESCO, etc.) to take the necessary steps to improve data availability.

Factors that matter most for ERA scores were found to be R&D expenditures, excellence of the Science and Technology Base, and productivity of the economy. Contrary to the suggestions of the expert group, international flows of knowledge, human resources and finance, as well as patenting in Grand Challenges have less statistical influence. Nevertheless, what concerns the ERA making, collaboration with world-wide research actors has a greater impact on ERA composite scores than collaboration restricted to Europe only.

The results obtained in this feasibility study should be considered with care before using them to provide insight into the nature of relevant policy challenges at EU scale. The team recommends also, for the follow-up of the project, to investigate a more structured framework for the ERA, expanding the number of dimensions and to identify and calculate some extra indicators to populate the framework in more detail.

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Introduction and objectives

The EU2020 strategy contains a blueprint for transforming Europe into an 'Innovation Union' by 2020. The recently published flagship initiative (October 6^{th}, 2010) commits the EU to boosting investment in research and making Europe an attractive place to develop innovative products. Consequently, national governments will have to reform their innovation systems to boost cooperation between industry and universities, ensure a modernization of framework conditions for enterprises, and a number of other measures to enhance cross-border cooperation and to embrace joint programming. All these innovation aspects need to be carefully monitored by policy-makers in the European institutions and Member states.

This feasibility study, entitled 'ERA monitoring', focuses on monitoring the progress of Europe towards the completion of the European Research Area (ERA), towards the structural change of national and super-national innovation systems and towards the modernization of higher-education institutions.

The project addresses the feasibility to develop three conceptual frameworks (organised in three work packages – WPs) and the potential to further aggregate the underlying components into composite indicators to measure:

WP 1:
progress in the construction and integration of a European Research Area (ERA), to monitor the overall performance of the Science and Technology system.

WP 2:
structural change, to consistently monitor the increase towards a more knowledge-intensive economy in Europe with the orientations of the EU 2020 strategy and the Innovation Union initiative.

WP 3:
research excellence in Europe, namely the effects of European and National policies on the modernization of research institutions, the vitality of the research environment and the quality of research outputs in both basic and applied research.

The present deliverable represents the outcome of WP 1 of the project.

The objective of this work-package is to test the feasibility to develop composite indicators to measure the progress made by Member States, EFTA countries, Candidate countries and Israel in the construction and integration of the ERA.

The study intends to cover EU27, EFTA, Candidate countries, Israel and a set of benchmark countries for as many years as possible, depending on data availability.

In this WP – as well as in WP2 and WP3, the steps mentioned in the OECD/JRC Handbook (OECD-JRC 2008) were followed:

<u>step1. Development of a theoretical framework</u> for the measurement of the overall progress towards the creation and integration of the ERA derived from the expert group report 'ERA indicators and monitoring' 2009 EUR 24171 EN.

The construction of the theoretical framework implies the following phases:

a. Use of the framework identified by the expert group in the 'ERA indicators and monitoring' report;

b. Collection of data sources for as many years as possible at country level for EU27 Member States, EFTA, Candidate countries and Israel. In relevant cases comparisons with at least the US, JP and China were done.

step2. Use of multivariate statistical tools to assess the suitability of the data set and to ease the understanding of the consequences of the methodological choices (e.g.: weighting and aggregation), during the construction phase of the composite indicator.
Statistical analysis was used for imputing missing data (if needed), detecting outliers, and suggesting suitable transformations of indicators due to skewness or kurtosis (if needed). Multivariate techniques (Principal Components Analysis - PCA) helped to decide if the nested structure of the composite indicator was well-defined and if the set of available individual indicators was sufficient or appropriate to describe the phenomenon. In this study PCA was used as a validation tool to identify the presence of a single latent component behind a theoretical dimension. We did not use PCA at this stage to revise the conceptual framework originally proposed by the Expert Group, nor as a weighting tool.

step3. Construction of the composite indicator. Several alternatives for the construction of the composite indicator were available:

a The normalization method for transforming the indicators to create a dimension-free set of variables (e.g. z-scores or min-max approach);
b The set of weights assigned to each indicator (e.g. statistical methods vs. stakeholder elicitation, vs. equal weighting, vs. country-specific weights based on data envelopment analysis);
c. The aggregation procedure for the individual indicators (linear or geometric) to obtain country-based and EU scores.

Given the time constraints only items a and c were investigated.

step4. Use of uncertainty and sensitivity analysis to check the robustness of the resulting composite scores to various types of uncertainty (in the data, in scale transformations, normalization, weights, different types of aggregation). The scope of uncertainty and sensitivity analysis is to acknowledge the variety of methodological assumptions involved in the development of the composite scores. In that way, one can determine whether the main results change substantially when the main assumptions are varied over a reasonable range of possibilities (Saisana *et al.*, 2005, Saltelli et al., 2008). A combination of uncertainty and sensitivity analysis can help to gauge the robustness of the composite indicator, to increase its transparency and to help framing a debate around it.

The aggregation methods can range from fully non - compensatory to fully compensatory, depending on the possible policy uses. Compensation, or trade-off, among underlying indicators is accepted when one is interested in the average country performance across indicators. Sometimes, the decision-maker considers this trade-off as a conflict that has to be resolved. This conflict can be treated in the light of a non-compensatory logic and taking into account the absence of preference independence within a discrete multi-criteria approach.

The ERA Headline Indicators

The expert group report ‘ERA indicators and monitoring’ defines its model of the ERA along two structural dimensions: 5 ‘components’ of the ERA (no details given here) and 4 ‘types of concern’ [4] :

type A1: “National Policy”, about policy actions at Member State level;
type A2: “Joint/coordinated Policies”, about policy actions at EU level;
type B: “ERA Making”, about progress in building the ERA;
type C: “ERA Effects”, about the impact of the ERA on the ex-Lisbon, now EU 2020 objectives.

from which a set of 18 headline indicators has been identified. The idea of the expert group is that an integrated assessment of the proposed headline indicators provides a good synthesis of progress towards the European Research Area. In Table 1, we report the indicators defined by the expert group.

Table 1: List of the headline ERA indicators proposed by the expert group

Code	Indicator	Definition
	NATIONAL POLICY (Type A1)	
H1	**Public investment in knowledge**	*Public funding of R&D and higher education as a share of GDP*
	JOINT/COORDINATED POLICIES (Type A2)	
H2	**European integration of research systems (policies)**	*Share of National Public Funds for Trans-nationally Coordinated Research*
	ERA MAKING (Type B)	
H3	**ERA research actors cooperation and cohesion**	*Share of co-publications (as regard to publications and to co-publications) which are with EU partners, among which with the 10 Member States with the lowest R&D intensity*
H4	**International cooperation in S & T and opening to the world (ERA Initiative)**	*Share of co-publications (as regard to publications and to co-publications) which are with non-EU partners*
H5	**Mobility of researchers and research careers (ERA Initiative)**	*Percentage of Doctoral degree Holders who obtained their doctorate in another EU country and/or have worked in another EU country*
H6	**Knowledge transfer between public and private sector (ERA Initiative)**	*Share of publicly-performed research which is financed by business*
H7	**Pan-European research infrastructures**	*Amount of funding committed to new pan-European research infrastructures in the framework of ESFRI, ERIC or other transnational agreements*
	ERA EFFECTS (Type C)	
H8	**Activity level in knowledge-producing activities**	*Share of R&D expenditures in the Gross domestic product (includes public and private)*
H9	**Strength of the Business research base of Europe**	*Business expenditure in R&D (BERD) / GDP or population; growth in real terms*
H10	**Excellence of the S&T Base**	*a) World share in top 10% most cited publications divided by world share of publications* *b) World share in top 250 most academic research intensive universities*
H11	**The Human Resource Base of the ERA**	*Importance of tertiary education graduates in Europe*
H12	**Transition towards a knowledge based economy - Structural change (1)**	*Evolution of the share of total value added contributed by sectors with higher proportions of tertiary educated employees*
H13	**Knowledge based innovation**	*% of innovators as a percentage of all firms (Innovation by firms based on own research as well as adaptation of knowledge developed by others)*
H14	**Firm Dynamics - Structural Change (2)**	*Percentage of high-growth firms*

H15	**International attractiveness of Europe for Business** **innovation and investment**	*Share of R&D expenditures by non-EU foreign affiliates in total business R&D expenditures and Share of R&D expenditures by non-EU foreign affiliates / their share of value added*
H16	**Productivity of the economy**	*Growth rate of labour productivity per hour both for the whole economy and for the knowledge intensive part of it*
H17	**Mobilising R&D to address Grand Challenges – Contribution of S&T to sustainable development and competitiveness**	*(a) Leadership: World shares of scientific publications and EPO applications in the fields of the Grand Challenges* *(b) Responsiveness: World shares of scientific publications and EPO applications in the fields of the Grand Challenges / World shares of scientific publications and EPO applications in all fields ('specialisation' in the fields of Grand challenges).*
H18	**Confidence of society in science and the S&T community**	*responses in survey expressing interest and confidence of the citizens in S&T*

The theoretical framework

Although the comprehensive set of indicators listed by the expert group potentially amounts to 60, in this study <u>we focus on the 18 ERA headline indicators</u> summarised above given that only for them the expert group gave a quantitative characterization, indicating its source and availability. These proposed indicators were, according to the expert group, mostly either available or feasible in the short term.

The theoretical framework would already be quite well set-up by the types of concern if it were not for the fact that concerns of type A1 and A2 had only one indicator each, whereas type B and type C concerns had 5 and 11 indicators, respectively.

With the above headline indicators in mind, organized along the four types of concern, we set up the <u>theoretical framework as composed of three domains</u>:

- the "inputs towards ERA implementation **(INP)**" composed by (H1, H2, H8, H9),
- the "ERA making **(MAK)**" composed by (H3, H4, H5, H6, H7), and
- the "outcomes of ERA **(OUT)**" composed by (H10 – H18).

The domain "inputs towards ERA implementation (INP)" is composed of indicators from concerns of type A1 and A2, with the addition of indicators H8 and H9, which measure shares of R&D expenditures in the GDP by the public and the private sectors. These indicators (4 in number) are indeed those which, according to our belief, <u>measure the inputs towards ERA implementation</u>, because they include both funding levels and policy actions for the coordination and opening-up of the funding for research. The indicators combine domestic and supranational financial efforts to realize an integrated European research system.

The 5 indicators of Type B concern compose exactly the second domain of our theoretical framework. Considering that indicator "H3: ERA research actors cooperation and cohesion" is actually composed by two indicators, one for cooperation and another for cohesion, which we define as MAK1 and MAK2. <u>The MAK domain intends to measure the interactions between actors in the higher education, national research and innovation systems.</u>

All the other indicators, i.e. the remaining 9 indicators of Type C concern, compose the domain “outcomes of ERA (OUT)”. OUT is meant to capture the realization of the knowledge society in terms of attractiveness and excellence of the European R&D and innovation system.
Indicator “H10: Excellence of the S&T Base” was actually composed of two indicators, one on publications and another for universities, we defined as OUT1 and OUT2. Moreover, considered that indicator “H17: Mobilising R&D to address Grand Challenges” was actually composed by two indicators, one on leadership and another on responsiveness, we defined as OUT9 and OUT10.

Table 2 provides the headline indicators structured along the domains of the proposed theoretical framework.

Table 2: Correspondence between headline indicators and domains

Headline indicators	New Codes
INP – inputs towards ERA implementation	
H1	INP1
H2	INP2
H8	INP3
H9	INP4
MAK – ERA making	
H3 (first part)	MAK1
H3 (second part)	MAK2
H4	MAK3
H5	MAK4
H6	MAK5
H7	MAK6
OUT – Outcomes of ERA	
H10 (first part)	OUT1
H10 (second part)	OUT2
H11	OUT3
H12	OUT4
H13	OUT5
H14	OUT6
H15	OUT7
H16	OUT8
H17 (first part)	OUT9
H17 (second part)	OUT10
H18	OUT11

Indicators, data availability and proxies

Hereafter, we provide some comments on a few individual indicators.

Indicator “INP2: share of national public funds to trans-nationally coordinated research” is a measure of the coordination and integration of the funding for research, which has only meaning within the ERA.

Similarly, indicators “MAK1 and MAK2: ERA research actors cooperation and cohesion” are meaningful when we want to measure the implementation of the ERA as they are a measure of cohesion within ERA. However, they make no sense when we want to benchmark the progress of the ERA as a whole with other countries (US, JP, CN, etc.).

For these reasons, we think that it is necessary to add a modified version to the main composite indicator. The main composite indicator includes, among others, indicators INP2, MAK1 and MAK2, in order to benchmark the countries inside the ERA. Its modified version (without INP2, MAK1 and MAK2) is necessary to compare the progress of the ERA against international benchmarks (e.g. US, JP, CN, etc.).

An additional observation about MAK1 and MAK2: the ERA is not only about EU27, but includes EFTA, Candidate countries and Israel. So, the indicator should include all these countries.

For each individual indicator a quality profile is provided in Table 3. For some indicators proxies had to be used due to poor data availability. In that case Table 3 displays both the unused original indicator and the adopted proxies. Detailed graphs for each indicator by countries are displayed in the Annex I at the end of this report.

Table 3: Quality profiles for the indicators of the proposed framework

INP1 – Public Investment in Knowledge
GOVERD + public expenditures at tertiary level of education as a share of GDP
Source: Eurostat, Unesco

Notes on the sources:
- Eurostat data on Government expenditure on R&D (GOVERD) and higher education expenditure was complemented with UNESCO data for missing countries and missing years for BRICS, Israel and South Korea.
- Time period: due to the limited availability of higher education expenditure data, indicator is in turn limited to year 2001-2007,
- Countries: partially availability for EU candidate countries

INP2 – European Integration of Research Systems
Share of National Public Funds for Trans-nationally Coordinated Research.
Source: Eurostat (experimental data collection)

Notes on the sources:
- Time period: new Government Budget Appropriations Outlays for R & D (GBAORD) statistics only computed for 2007 and 2008 by Eurostat
- Countries: Since trans-nationally coordinated research refers to the European level, this data is only relevant for ERA countries; yet ERA countries are only partially available. Quality can increase once GBAORD statistics are more available.

INP3 - Activity level in knowledge producing activities
Total intramural R&D expenditure divided by GDP (PPP): GERD/GDP
Source: Eurostat

Notes on the sources:
- Time period: 1995-2009 available
- Countries: almost complete coverage, except for FYRO Macedonia, Liechtenstein, Israel, Brazil, India and South Africa.

INP4 – Strength of business research base
Business expenditure in RD (BERD) / GDP
Source: Eurostat

Notes on the sources:
- Time period: 1995-2008 available
- Countries: almost complete coverage, except for FYRO Macedonia, Liechtenstein, Israel, Brazil, India and South Africa.

MAK1 – ERA research actors (cooperation)
Share of co-publications (publications & co-publications) which are with EU partners
Source: Science Metrix (Scopus)

Notes on the sources:
- Time period: 2000-2009 available,
- Countries: EU candidate countries, EFTA, Israel, and 2 BRICS data are missing.

MAK2 – ERA research actors (cohesion)
Nr. of co-publications with the 10 Lowest RD EU Partners / Total nr. of publications
Source: Science Metrix (Scopus)

Notes on the sources:
- Only meaningful for composite at ERA level,
- Co-publications were only computable for country pairs, thus not free of double counting,
- Time period: aggregate of period 2000-2009,
- Countries: ERA (except FYRO Macedonia and Liechtenstein).

MAK3 – International cooperation in S & T and opening to the world
Share of co-publications which are with non-EU partners
Source: Science Metrix (Scopus)

Notes on the sources:
- Co-publications for EU-27 member states counted if affiliations include one or more EU-27 MS and at least one other country, so this indicator should, by definition, not be anti-correlated with indicator MAK1.
- For EU-27 total as well as US, Japan, China, Brazil and South Korea, the number of international collaborations with each other are counted as co-publications,
- Time period: 2000-2009 available,
- Countries: data is available for EU-27, Brazil, China, South Korea Japan and USA.

MAK4 – Mobility of researchers and research careers

<u>Original indicator not used</u>
Percentage of Doctoral degree Holders who obtained their doctorate in another EU country and/or have worked in another EU country
Source: OECD, Eurostat

Notes on the source:
- Defined by the share of researchers who have worked in the last three years for at least 3 months in a country other than the country where they attained their highest educational degree after (highest-degree) graduation,
- Status: under development,
- Time period: data availability very limited (2009 only),
- Countries: <u>data availability very limited</u> (8 EU-27 countries only).

<u>Alternative used:</u>
Share of Doctoral candidates with the Citizenship of another EU-27 Member State in the reporting Country
Source: Eurostat, MORE Higher Education Sector survey (DG-RTD)

Notes on the sources:
- Time period: 2004-2007 available,
- Countries: data is available for 18 EU-27 Member States in 2004 and for 22 EU-27 Member States in 2007.

<u>Second alternative not used</u>
Nr. Doctoral candidates from other EU and extra-EU countries /Total nr. of doctoral candidates
Source: OECD Careers of Doctorate Holders Survey, 2006 basic indicators
Notes on the source:
- Percentage of national citizens with a doctorate having lived/stayed abroad in the past ten years - Doctorate holders below 70 years old who received their doctoral degree between 1990 and 2006 (%),
- Time period: data availability very limited (2006 only),
- Countries: data availability very limited (9 EU-27 countries only).

<u>Third alternative not used</u>
Share of Doctoral candidates from other EU and extra-EU countries (%)
Source: OECD
Notes on the sources:
- International students defined as "non-resident students". Although preferred indicator for international students in the EU would be students who "pursued prior education in another country", but data was only available for 2 countries,
- Time period: data availability limited (2004 to 2008),
- Countries: data availability limited (9 EU-27 countries only).

MAK5 – Knowledge transfer between public and private sector
HERD financed by business + GOVERD financed by business / BERD
Source: Eurostat, OECD

Notes on the sources:
- Time period: 1995-2009 available,
- Countries: almost complete coverage, except for FYRO Macedonia, Liechtenstein, Israel, Brazil, India and South Africa.

MAK6 – Pan-European research infrastructures
Original indicator not used because of lack of data
Amount of funding committed to new pan-European research infrastructures in the framework of ESFRI, ERIC or other transnational agreements
Source: Eurostat (experimental data collection)

Notes on the sources:
- Covers national contributions to trans-national public R&D performers (i.e. CERN, ILL, ERSF, EMBL, EMBO, ESO, JRC),
- Time period: 2007-2008 available,
- Countries: EU-27 and EFTA partial data set; EU candidate countries, Israel, BRICS, USA, Japan data are missing.

OUT1 – Excellence of the S&T Base (publications)
Original indicator not used because too biased towards small countries
World share in top 10% most cited publications divided by world share of publications
Source: Science Metrix (Scopus)
Notes on the sources:
- Time period: 2000-2007 available,
- Countries: complete coverage, except for South Africa.

Alternative used
World share in top 10% most cited publications
Source: Science Metrix (Scopus)
Notes on the sources:
- Time period: 2000-2007 available,
- Countries: complete coverage, except for South Africa.

OUT2 – Excellence of the S&T Base (Universities)
Nr. Academic research intensive Universities & Public research orgs in Top250, divided by population
Source: The Leiden Ranking, Eurostat
Notes on the sources:
- Leiden Ranking 2008, 2010: Number of universities in World Top 250; "Lighter Green ranking by the size-independent, field-normalized average impact, the CWTS crown indicator CPP/FCSm",
- Time period: for 2 years only: 2008 and 2010,
- Countries: complete coverage, however, 14 EU-27 member states, 5 other ERA countries, India and South Africa have no universities among the top 250.

OUT3 – The Human Resource Base of the ERA
Percentage of population aged 25 – 34 with tertiary education
Source: Eurostat

Notes on the sources:
- Time period: 2000-2010 available,
- Countries: Liechtenstein, Israel, China and India's dataset are missing.

OUT4 – Transition towards a knowledge based economy - Structural change
The share of total value added contributed by sectors with higher proportions of tertiary educated employees
Source: OECD

Notes on the sources:
- Knowledge based sectors include high-technology manufacturing (DG24.4, DL30, DL32, DL33, DM35.3) and knowledge-intensive, high-technology services (I64, K72 and K73),
- Time period: 1995-2007 available,
- Countries: for Ireland, Luxembourg, Poland, Portugal and Iceland data are missing for one or more sectors; EU candidate countries, Liechtenstein, Israel and BRICS data set missing.

OUT5 – Knowledge-based innovation
Innovators as a percentage of all firms (within CIS sample)
Source: Eurostat Community Innovation Survey (CIS)

Notes on the sources:
- Time period: for CIS years 1996, 2000, 2004, 2006 and 2008,
- Countries: covers EU member states in CIS, plus partially available data for Croatia, Turkey, Iceland and Norway.

OUT6 – Firm Dynamics - Structural Change
Percentage of high-growth firms
Source: Eurostat

Notes on the sources:
- High growth enterprises are those with average annualized growth rate greater than 20% per annum, over a three year period, in terms of employment or turnover,
- Time period: only available for 2005-07,
- Countries: partially populated dataset: 18 EU-27 Member States and Norway.

OUT7 – International attractiveness of Europe for Business innovation and investment
Original indicator not used
Share of business R&D financed from abroad by enterprises within the same group in total business R&D
Source: OECD

Notes on the sources:
- Data on R&D expenditures by foreign affiliates located in non-EU countries is not available,
- Time period: 2003-2008 available,
- Countries: partially populated dataset, EU-27, EU candidate countries, Israel, BRICS, Japan and USA dataset missing.

Alternative used
BERD financed by abroad
Source: Eurostat, OECD

Notes on the sources:
- Distinction between EU and non-EU countries as source of financing, not available,
- Time period: 1995-2009 available,
- Countries: EU-27, EU candidate countries, EFTA, Russia, China, South Africa, South Korea and Japan dataset available. A major trend break was found in the case of Latvia between 2002 and 2003.

OUT8 – Productivity of the economy

Original indicator not used
Growth rate of labour productivity per hour both for the whole economy and for the knowledge intensive part of it
Source: OECD, partially available
Notes on the sources:
- Labour productivity for whole economy: GDP per hour, in 2010 USD PPP,
- Labour productvitiy per hours data unavailable for knowledge-intensive sectors,
- Time period: 1995-2009,
- Countries: All countries, except Bulgaria, Cyprus, Lithuania, Latvia, Malta, Romania, Croatia, FYRO Macedonia, Turkey, Lichtenstein, BRICS.

Alternative indicator used
Labour productivity per hour for the whole economy
Source: The Conference Board Total Economy Database, January 2011, http://www.conference-board.org/data/economydatabase/ (OECD, Eurostat, National accounts included)

Notes on the sources:
- Labour productivity for whole economy: GDP per hour, in 2010 EKS$,
- Labour productivity per hours data unavailable for knowledge-intensive sectors,
- Time period: 1995-2010,
- Countries: All countries, except Croatia, FYRO Macedonia, Russia, China and India.

OUT9 – Mobilising R&D to address Grand Challenges (leadership)
World shares of scientific publications and European patent office (EPO) applications in the fields of the Grand Societal Challenges
Source: OECD, EPO

Notes on the sources:
- Patents in grand societal challenges include the following technology fields: energy generation from renewable and non-fossil sources; technologies specific to climate change mitigation; emissions abatement and fuel efficiency in transportation; energy efficiency in buildings and lighting; and health-related technologies: IPC classes A61B-K; H05G,
- For international comparison, indicator is based on applications filed under PCT,
- Data on scientific publications in grand societal challenges are unavailable,
- Time period: 1995-2009 available,
- Countries: complete coverage.

OUT10 – Mobilising R&D to address Grand Challenges (responsiveness)
World shares of scientific publications and EPO applications in the fields of the Grand Societal Challenges / World shares of scientific publications and EPO applications in all fields ('specialisation' in the fields of Grand Societal Challenges).
Source: OECD, EPO

Notes on the sources:
- Patents in grand societal challenges include the following technology fields: energy generation from renewable and non-fossil sources; technologies specific to climate change mitigation; emissions abatement and fuel efficiency in transportation; energy efficiency in buildings and lighting; and health-related technologies: IPC classes A61B-K; H05G,
- For international comparison, indicator is based on applications filed under PCT,
- Data on scientific publications in grand societal challenges are unavailable,
- Time period: 1995-2009 available,
- Countries: complete coverage.

OUT11 – Confidence of society in science and the S&T community
Responses in survey expressing interest and confidence of the citizens in S&T
Source: Commission - Eurobarometer

Notes on the sources:
- Eurobarometer Special Surveys on Science and Technology were conducted in 2001, 2005 and 2010; however, 2001 survey unavailable at country level,
- Interpreted as share of respondents with at least 'moderate' interest in "new inventions and technologies" (2005 survey) or "New scientific discoveries and technological developments" (2010 survey),
- Time period: 2005 and 2010,
- Countries: EU-27, candidate and EFTA countries.

Despite the considerable efforts made to gather data for the indicators, a majority of them were not available as sufficiently long time series. Sometimes only values at one single time point were found. In order to be able to show some trend, we decided to choose two reference time points: approximately at the beginning of the Lisbon strategy (*begin Lisbon*), i.e. with data around year 2000-2002, and approximately at the beginning of the EU-2020 strategy (*begin EU-2020*). In this latter case, the data were considered for the most recent year available, i.e. 2007-2010. In the following we indicate these two reference periods as *begin Lisbon* and *begin EU-2020*.

Tables 4 and 5 show overall data availability by country and by indicator for both reference periods *begin Lisbon* and *begin EU-2020*.

In the domain INP we had generally very good coverage except for indicator INP2, which only had data available for *being EU-2020* (44%). These data were compiled by Eurostat but are not yet publicly available because they are part of an experimental data collection. As we do not recommend imputation under such low data availability, we decided not to include INP2 in the composite indicator, expecting better Eurostat data to be produced in the future.

The domain MAK was the most problematic of the three domains in terms of data availability.
For MAK2 we had data on an aggregated period 2000-2009 from Science Metrix. Data for each time point in the range 2000-2009 will hopefully be available in September 2011. For the moment, we used the same aggregated values for both monitoring periods, i.e. *begin Lisbon* and *begin EU-2020*.
We were obliged to use a proxy for indicator MAK4, for which no data are available; this enabled us to reach 49% availability for *begin Lisbon* and 54% availability for *begin EU-2020*.

For indicator MAK6 no data were available in *begin Lisbon* and only 21% of the data were available in *begin EU-2020*. Similar to INP2, the data were compiled by Eurostat as part of an experimental data collection. As we do not recommend imputation under such low data availability, we decided not to include MAK6 in the composite indicator, expecting better Eurostat data to be produced in the future.

In the domain OUT, indicator OUT1, an indicator of specialization in publications, is extremely biased towards small countries, and would have corrupted the results. We decided to consider only the numerator of this indicator, which is anyway a consistent measure of excellence. Indicators OUT2 and OUT6 had data available only for *begin EU-2020* (40%). For this reason we decided to omit OUT6 from the analysis.
For the indicator OUT7 originally proposed by the expert group no data were available at *begin EU-2020* and only 23% were available at *begin Lisbon*. Using the proxy indicator proposed by the expert group the rate of availability reached 83% at each year.
The source suggested by the expert group for indicator OUT8 had no data available for the knowledge part of the economy; we decided to use a proxy for OUT8, which provided the best alternative for the total economy. Moreover, we believed that labor productivity levels were better suited to measure outcomes of ERA than labor productivity growth rates.
For indicator OUT11 only two survey years with country specific results were available: 2005 and 2010. So we decided to include the 2005 survey in the *begin Lisbon* reference time point.

We had also to reduce the original list of countries considered in the study (see Table 4), eliminating three countries with very low rate of data availability – FYROM and Lichtenstein for the ERA and South Africa for the international benchmark, as this would not have allowed us to evaluate the composite indicator.

Table 4: data availability (in %) by country for time points *Begin Lisbon* and *Begin EU-2020*. Availability below 60% is shown in red.

Group	Country	*Begin Lisbon*	*Begin EU-2020*
EU-27	Austria	70	95
	Belgium	80	95
	Bulgaria	75	90
	Cyprus	75	90
	Czech Republic	80	100
	Germany	75	90
	Denmark	80	95
	Estonia	75	95
	Greece	75	75
	Spain	80	100
	Finland	80	95
	France	75	90
	Hungary	80	100
	Ireland	75	85
	Italy	75	95
	Lithuania	75	85
	Luxembourg	65	80
	Latvia	70	90
	Malta	65	85
	Netherlands	75	90
	Poland	80	95
	Portugal	80	100
	Romania	75	90
	Sweden	80	95
	Slovenia	75	95
	Slovakia	80	100
	United Kingdom	80	90
AGGREGATED EU-27		55	70
Candidate Countries	Croatia	45	75
	Turkey	50	70
	FYROM	Not considered	
EFTA	Switzerland	50	70
	Iceland	65	75
	Norway	65	85
	Lichtenstein	Not considered	
Other	Israel	35	50
BRIC	Brazil	50	60
	Russia	40	50
	India	35	40
	China	55	55
	South Africa	Not considered	
Other international benchmarks	South Korea	60	70
	Japan	60	70
	United States	55	65

Table 5: data availability (in %) by indicator for time points *Begin Lisbon* and *Begin EU-2020*.
(Availability below 60% is shown in red. Indicators INP2, MAK6 and OUT6 were omitted from the analysis.)

Indicators	*Begin Lisbon*	*Begin EU-2020*
INP1	93	93
INP2	0	44
INP3	100	100
INP4	100	100
MAK1	78	78
MAK2	0	80
MAK3	80	80
MAK4	49	54
MAK5	83	88
MAK6	0	21
OUT1	100	100
OUT2	0	100
OUT3	73	95
OUT4	63	63
OUT5	71	78
OUT6	0	40
OUT7	83	83
OUT8	98	98
OUT9	100	100
OUT10	100	100
OUT11	80	80

Treatment of outliers

The results of the composite indicator could be sensitive to the presence of outliers, which, if not treated properly, could lead to incorrect benchmarks. Furthermore, outliers can have a strong impact on the correlation structure (see next section on multivariate analysis), and hence introduce bias in the composite indicator and in the subsequent interpretation of the results.
There are many methods suitable for outlier detection, but in the context of composite indicator building the use of skewness could be particularly apt. A skewness value greater than 1 could flag problematic indicators that need to be treated before constructing the composite.

- We found high skewness (3.8) for indicator 'MAK5: Knowledge transfer between public and private sector'. This was due to extremely high values for Lithuania and Latvia at *begin Lisbon*. We realised that the official BERD values were wrong, resulting in shares for MAK5 higher than 100%. So we decided to remove those values.

- For indicator 'OUT7: International attractiveness of Europe for Business innovation and investment', the skewness level of 5.6 was reduced to 1.0 by censoring the values of Latvia at the *begin Lisbon* time point, for the same reason as in the previous item.

Imputation of missing values

The values available at *begin EU-2020* for MAK2 and OUT2 were imputed at *begin Lisbon*, since these indicators had no observations at *begin Lisbon*.
For the remaining missing observations we tested two types of imputation techniques which are different in nature. In the first one, we applied hot-deck imputation[2] using Manhattan distance (i.e. the

[2] Hot-deck imputation is a means of imputing missing data using the data from other observations in the sample at hand, preserving the distribution of item values. The term "hot deck" dates back to the storage of data on punched cards, and

sum of the absolute differences of their coordinates) to the two nearest neighbours (see OECD-JRC 2008, p.55). The second imputation was based on statistical correlation among pairs of indicators (see OECD-JRC 2008, pp.56-57).

Multivariate statistical analysis

We used the statistical software STATA® and STATISTICA® to perform a series of descriptive uni- and multivariate statistical analyses on the three domains of the theoretical framework, i.e. on INP, MAK and OUT. We executed these analyses both before and after the imputation of missing values and verified that the imputation maintained unchanged the statistical structure of the data. We show the results hereafter.
Throughout this report, we used Principal Component Analysis (PCA) as statistical validation tool to identify whether there is a latent component described by the set of indicators of the respective domain. If there is one clear component, then we are sure that the indicators in that domain contribute altogether to the identification of that latent dimension. Otherwise we conclude that the domain is not statistically coherent and a revision of the framework is required. We do not intend to use PCA as a weighting tool, although this is often found in the literature.

On the domain INP: we noticed a very high correlation between INP3 and INP4 (.99)[3] in both time points considered. This led us to eliminate one of the two indicators or, alternatively, halve the weight associated to each of them in the forthcoming aggregation stage.
The (PCA) executed at the *begin Lisbon* time point showed one very clear component, explaining 85% of the data variance. This meant that behind indicators INP1, INP3 and INP4 there was a single underlying concept. The factor loadings estimated for the first component showed that all three indicators concurred to characterize the 'inputs' dimension of the ERA.
The situation was similar at the *begin EU-2020* time point where the PCA showed one component explaining 81% of the data variance with all indicators contributing at about the same extent to describe the INP domain.

Recommendation: In the feasibility study INP2 was not used. We suggest, for the follow-up project, to check whether data for indicator INP2 are available at the begin EU-2020 time point for the missing countries, and test (using PCA) whether the structure of INP are characterized by one single component. If two components are present, we then can foresee a revision of the INP domain, by splitting it into two sub-domains.

On the domain MAK: the phenomenon of ERA making (MAK) was intrinsically complex and was quantified through five quite heterogeneous indicators showing a correlation matrix with both positive and negative values. The highest positive correlation observed was between "MAK1: Research actors - cooperation" and "MAK5: knowledge-transfer between public and private sectors" (0.64 at *begin Lisbon*) and between "MAK3: co-publications with non-EU countries" and "MAK4: mobility of doctoral candidates" (0.62 at *begin EU-2020*). The highest negative correlation (-0.5) was observed, at both years, between "MAK4: mobility of doctoral candidates" and "MAK5: business financing RD". This was due to countries performing well in MAK5, but low in MAK4 (i.e. BG, EE, LT, LU, LV and TR, and conversely, AT, BE, DE, NL and UK).[4] The negative correlation disturbed the forthcoming process of indicators aggregation, as it created an intrinsic undesired compensability effect between MAK4 and MAK5.

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indicates that the information donors come from the same dataset as the recipients. The stack of cards was "hot" because it was currently being processed. Cold-deck imputation, by contrast, selects donors from another dataset.

[3] In the best case our sample has 41 observations. The corresponding level of significance of the correlation coefficients (two-tails at $\alpha=0.05$) is about 0.3. This means that all correlation coefficients above 0.3 or below -0.3 are statistically significant.
[4] As it has been later found in WP3 of the ERA Monitoring project, a better normalization for MAK5 would be using GDP instead of BERD.

The PCA executed at the *begin Lisbon* time point actually showed two main components which jointly explained 75% of the data variance and a third component, which added another 10%. The PCA carried out at the *begin EU-2020* time point showed two main components which jointly explained 68% of the data variance and two additional components, to explain 94% of the data variance.
The structure of the MAK domain was characterized by many underlying dimensions, while the ideal situation would have been the existence of only one clear component. At this feasibility stage, we tested a composite measure of the overall heterogeneous process of ERA making, but for the follow-up of the project we propose to investigate a finer framework structure with sub-domains and underlying indicators.

Recommendation: The five indicators should ideally be replaced by sub-domains representing publications, mobility, infrastructures and financial flows, each of them possibly described by a set of indicators. This revision could be addressed in the follow-up of the project.

On the domain OUT: this domain was also composed of a quite heterogeneous set of indicators, which measured both detailed as well as very broad outcomes of ERA in terms of, among others, bibliometric and macro-economic indicators.
The correlation matrix did not contain negative elements, meaning that there were no antithetic directions spanned by the underlying indicators. The highest correlations (around 0.6 – 0.7) were:

- between OUT1 (excellence - Publications) and OUT2 (excellence - Universities),
- between OUT1 (excellence - Publications) and OUT5 (knowledge-based innovators)
- between OUT1 (excellence - Publications) and OUT8 (productivity);
- between OUT5 (knowledge-based innovators) and OUT8 (productivity); and
- between OUT8 (productivity) and OUT11 (interest in S&T).

The PCA executed at *begin Lisbon* time point actually showed three main components which jointly explained barely 64% of the data variance and another four components were necessary to explain almost 90% of the data variance. The PCA carried out at the *begin EU-2020* time point showed four main components which jointly explained 71% of the data variance and three additional components are required to just exceed 90%. Here, the same conclusions obtained for domain MAK could be drawn. The structure of domain OUT had many underlying dimensions, meaning that within this domain there were certainly other sub-domains that might be emphasized, and for each of them a set of indicators could be identified.

Recommendation: The indicators of the OUT domain should ideally be replaced by a number of framework dimensions, each of them possibly described by a set of indicators. This thorough revision should be addressed in the follow-up of the project.

A certain degree of positive correlation across domains was observed between the indicators of the INP domain and OUT1 (excellence – Publications), OUT2 (excellence - Universities), OUT5 (knowledge-based innovators), and OUT8 (productivity). Some negative correlations (about -0.5) were observed between MAK5 and INP3, INP4, OUT1, OUT5. For all these cases we believed that the correlation was not a factual linkage between these pairs of indicators. This problem occurred among different domains, hence it was less serious than the reported negative correlation observed between MAK4 and MAK5.

Building the composite indicators

Let us summarise the data situation after the decision to omit INP2, MAK6 and OUT6 from the analysis and before starting constructing the composite indicators. The three domains INP, MAK and OUT are composed of 3, 5 and 10 underlying indicators.

As said earlier, we developed two different composite indicators. The first includes indicators MAK1 and MAK2 (which are measures of cohesion within the ERA)[5] in order to benchmark countries within the ERA. The modified composite excludes indicators MAK1 and MAK2 with the aim to compare EU27 against other international benchmarks (US, Japan, South Korea, BRIC).

Table 6: Domains and indicators

Indicators	Definition
INP – inputs towards ERA implementation	
INP1	*GOVERD + public expenditures at tertiary level of education as a share of GDP*
INP3	*Total intramural R&D expenditure divided by GDP (PPP)*
INP4	*Business expenditure in RD (BERD) / GDP*
MAK – ERA making	
MAK1	*Share of co-publications (publications & co-publications) which are with EU partners*
MAK2	*Nr. of co-publications with the 10 Lowest RD EU Partners / Total nr. of publications*
MAK3	*Share of co-publications which are with non-EU partners*
MAK4	*Share of Doctoral candidates with the Citizenship of another EU-27 Member State in the reporting Country*
MAK5	*HERD financed by business + GOVERD financed by business / BERD*
OUT – Outcomes of ERA	
OUT1	*World share in top 10% most cited publications divided by world share of publications*
OUT2	*Nr. Academic research intensive Universities & Public research orgs in Top250, divided by population*
OUT3	*Percentage of population aged 25 – 34 with tertiary education*
OUT4	*Evolution of the share of total value added contributed by sectors with higher proportions of tertiary educated employees*
OUT5	*Innovators as a percentage of all firms (within CIS sample)*
OUT7	*BERD financed by abroad*
OUT8	*Level of labour productivity per hour for the whole economy*
OUT9	*World shares of scientific publications and European patent office (EPO) applications in the fields of the Grand Societal Challenges*

[5] it should have also included INP2, but this was dropped for other reasons

OUT10	*World shares of scientific publications and EPO applications in the fields of the Grand Societal Challenges / World shares of scientific publications and EPO applications in all fields ('specialisation' in the fields of Grand Societal Challenges).*
OUT11	*Responses in survey expressing interest and confidence of the citizens in S&T*

Main composite indicator: performance of ERA Countries

We began this phase of calculation of the overall composite indicator by considering eight different scenarios, which were obtained composing two alternative approaches for the normalization of the individual indicators (min-max and z-scores), with two alternative approaches for the aggregation (arithmetic average and geometric average across domains), and with other two alternative approaches for imputation (hot-deck and correlation-based).

The imputation, normalization and aggregation processes leading to the 8 scenarios:

	Imputations	Normalization	Aggregation
Original dataset	Hot-deck	min-max	Geometric
			Arithmetic
		z-scores	Geometric
			Arithmetic
	Correlation-based	min-max	Geometric
			Arithmetic
		z-scores	Geometric
			Arithmetic

Min-max and z-scores are the two most common techniques used to normalize the set of indicators prior to aggregation. The normalization process intends to remove the dimensions of all indicators so that they can be summed up. With the min-max normalization all indicators are transformed linearly such that they all range over the unit interval. With the z-scores normalization, the indicators are transformed linearly such that the average country has a normalized value of zero and all indicators have standard deviation of one across the countries. Both normalizations were carried out on all time points in conjunction, in order to be able to measure evolution. For details see OECD-JRC (2008).

The most common approach to build a composite indicator is to linearly aggregate all indicators within each domain with weights that are inversely proportional to the number of indicators in each domain. In this way a composite score for all countries in each domain is obtained. In a second stage, another linear aggregation can be carried out across the three domains (using equal weights) or, alternatively, a geometric aggregation (still with equal weights) can be used. A geometric aggregation is a partially non-compensatory aggregation in which necessary condition for a country to have a high score for the overall composite is that the country is high in each domain. Just one low score for a single domain inhibits a high score for the overall composite (OECD-JRC, 2008).

The results for the eight scenarios were quite similar[6], so we decided to represent one of them in Figure 1 (the combination min-max with arithmetic average, based on hot-deck imputation) and all of them in Figure 2. In this latter figure each country performance is not represented by a single score but by an interval including the eight rankings resulting from the eight scenarios. In both figures the composite scores and rankings are provided for both time points, *begin Lisbon* and *begin EU-2020*. The composite scores and rankings were also computed for non-ERA countries for completeness, although the comparisons of ERA countries with US, JP, CN, etc., made less sense because indicators MAK1 and MAK2 were not relevant to these countries.

[6] The correlation between the rankings obtained from the various scenarios was between 0.97 and 1.00, with the lowest values observed when different imputation methods were used.

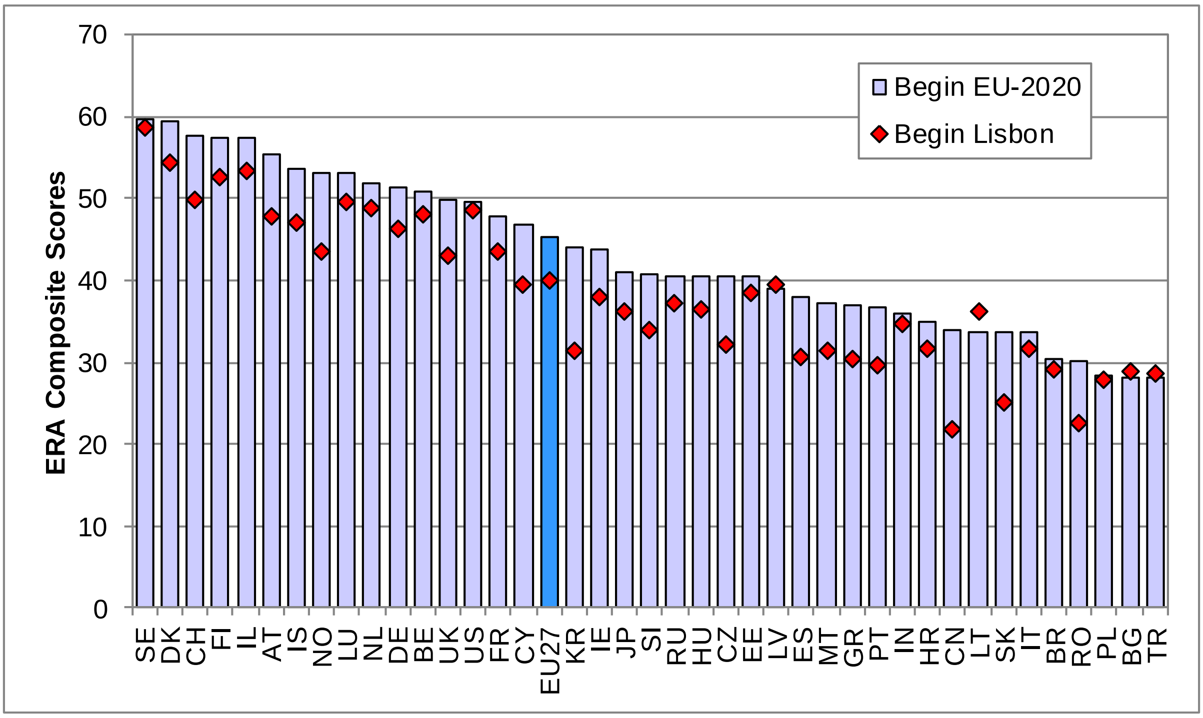

Figure 1: The overall ERA composite scores for the European Countries at *begin Lisbon* and *begin EU-2020* time points.

Looking at Figure 1, we observe the following:

Almost all ERA countries improved their performance over the period *begin Lisbon* and *begin EU-2020*. Those with the largest growth (above 20%) are Slovakia, Romania, Czech Republic, Spain, Portugal and Norway. The most advanced are the Scandinavian and EFTA countries, with Austria and Luxembourg. The group of Central European Member States belonging to the former EU-15 follow, though they are still above the EU27[7]. Below average we find all New Member States (except for Cyprus), with Spain, Greece, Portugal and Italy.

[7] Note that the values for EU27 express the weighted average across Member States at the level of underlying indicators as well as composite scores.

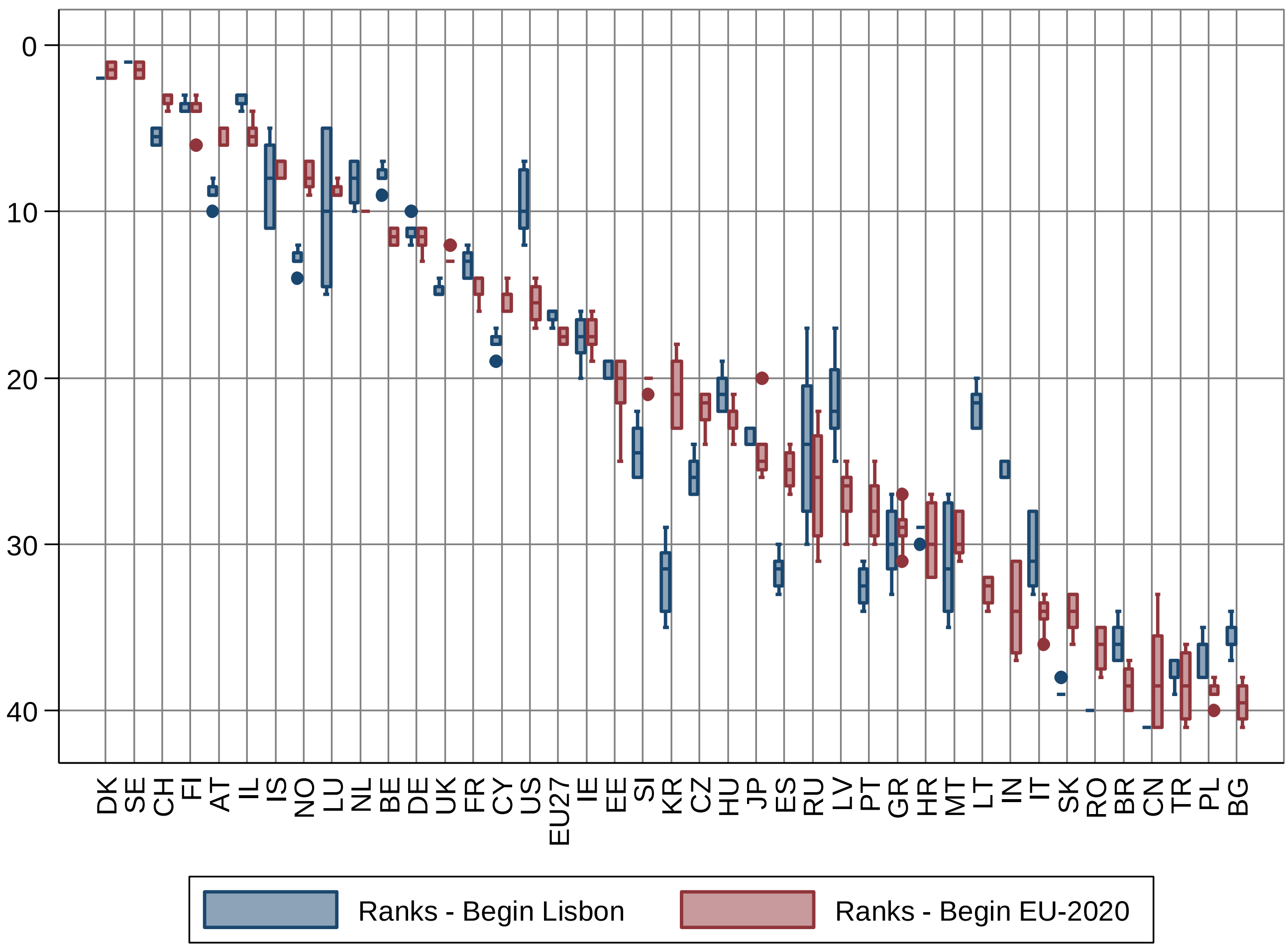

Figure 2: Box plot of ERA composite rankings for all countries at *begin Lisbon* and *begin EU-2020* time points
Note: Eight scenarios included are based on min-max and z-scores normalization, arithmetic and geometric aggregation, and hot deck and regression imputation methods

The objective of the uncertainty analysis is to test whether the country classifications are robust or volatile with respect to changes in the methodological assumptions, which are here identified by the eight different scenarios employed. Figure 2 shows all eight scenarios together in the form of an interval encompassing all eight rankings.

Sweden and Denmark are the best performers among the ERA Countries (both countries ranking first in 4 out of 8 scenarios at *begin EU-2020* while Sweden ranked always first at *begin Lisbon*). Then the intervals start partially overlapping across neighbouring countries but they are clearly separated for other pairs of countries. We identified three clusters of country performances despite the uncertainty in the way the composite was built. One is the cluster formed by the Scandinavian countries in *begin EU-2020* with Switzerland and Austria. This clearly outperforms the cluster composed by Belgium, Cyprus, France, Germany and United Kingdom. A third cluster consists of countries from South and East Europe.

For the group of countries for which the ranks are robust, signals derived from the composite can be taken with the confidence that changes in the methodology would have a negligible effect on the country's measured performance. For the group of countries with volatile scores, a more cautious approach is advised before translating the composite results into policy actions or naming-shaming narratives.

Despite the robustness, some countries show volatility. The largest volatility at *Begin Lisbon* are Luxembourg, Malta and Latvia, which may suffer from a small country bias. The rank for Luxembourg varies from 5 to 15, while that for Malta and Latvia varies from 27 to 35 and 17 to 25, respectively.

Countries in the lower ranks have slightly higher volatility than those at the higher ranks, which results from the selection of the imputation method.

For Luxembourg and Malta it is not possible to conclude whether they have improved between *begin Lisbon* and *begin EU-2020* as their rank intervals overlap. The same can be said for Iceland, Finland, Germany, Ireland, Estonia, Hungary, Greece, Croatia and Turkey. On the other hand, clear improvement can be noticed for Switzerland, Austria, Norway, the United Kingdom, Cyprus, Slovenia, the Czech Republic, Spain, Portugal, Slovakia and Romania.

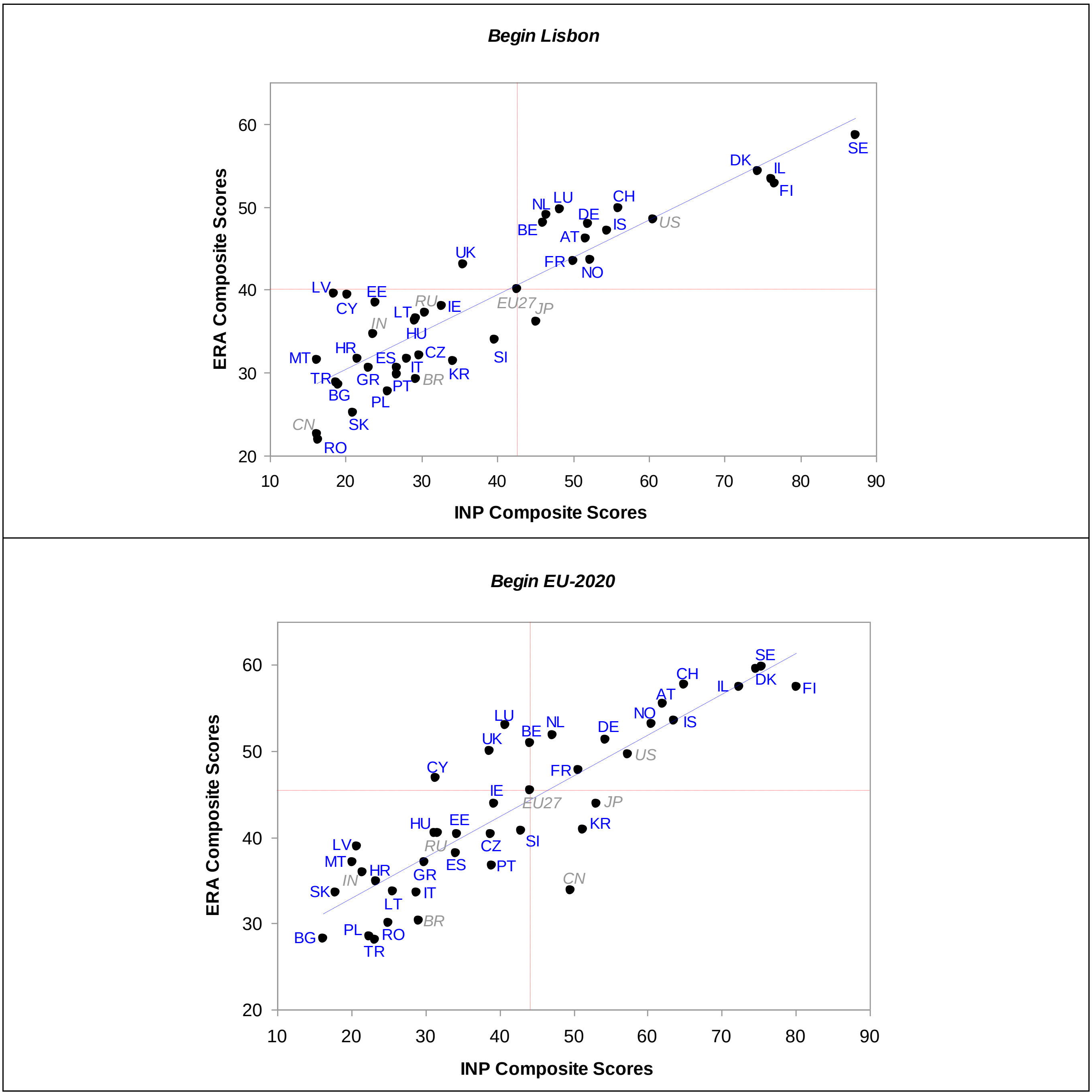

Figure 3: overall ERA composite scores against INP domain composite scores at *begin Lisbon* and *begin EU-2020* time points for ERA countries

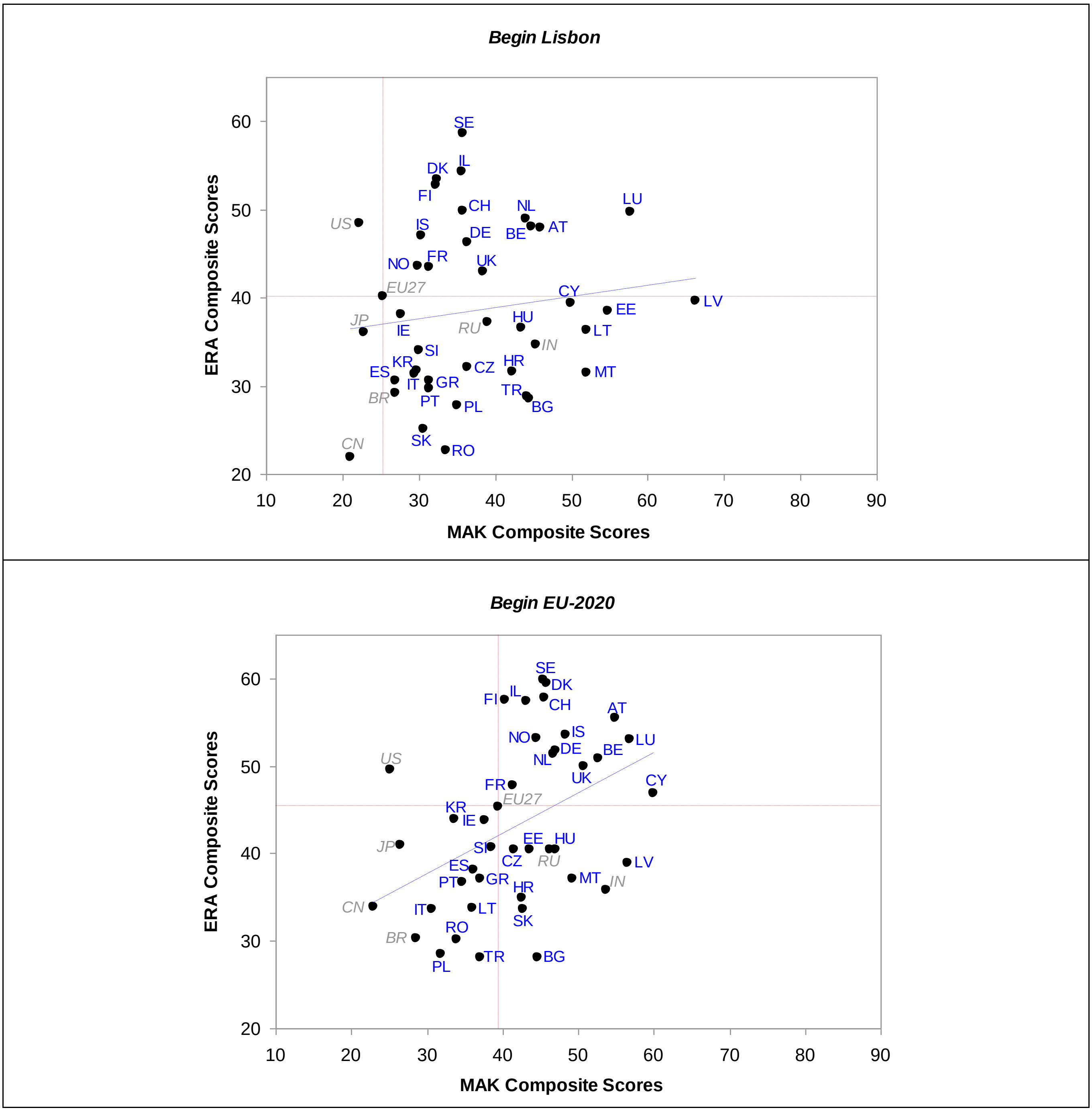

Figure 4: overall ERA composite scores against MAK domain composite scores at *begin Lisbon* and *begin EU-2020* time points for ERA countries

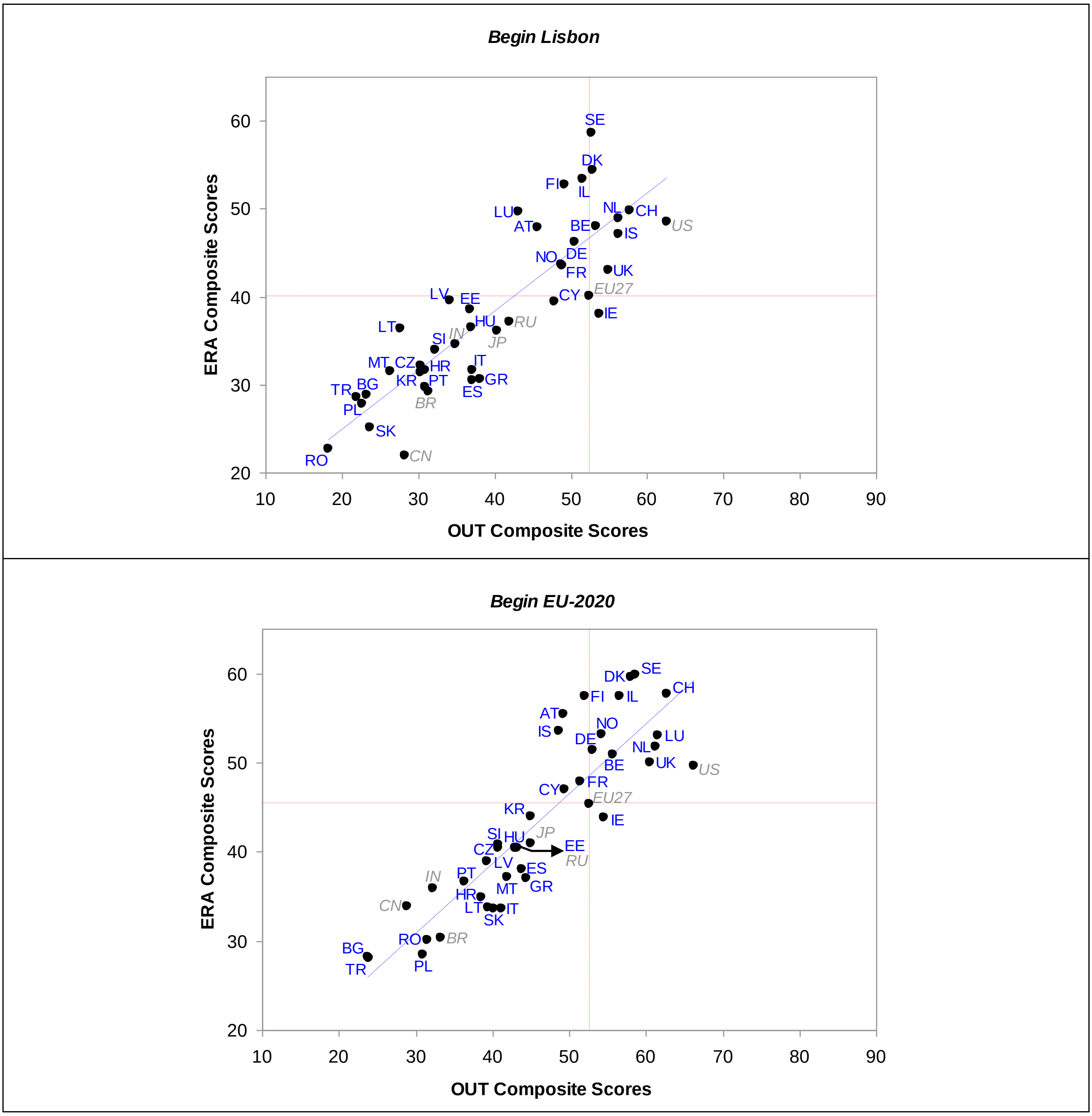

Figure 5: overall ERA composite scores against OUT domain composite scores at *begin Lisbon* and *begin EU-2020* time points for ERA countries

Figures 3, 4 and 5 show the scatter-plot of the overall ERA composite[8] against each domain of the framework, for each year separately. The scatter-plots show the presence of a pattern between each domain and the overall composite, meaning that the composite indicator is consistent with all its domains, because higher scores for a domain correspond to higher scores for the composite. However, the pattern in Figure 4 is the weakest because the slope of the regression line is the lowest. This means that for a unit improvement of the score of MAK the composite score improves less than for corresponding unit improvements of INP and OUT. In conclusion, the domain MAK has the weakest influence on the ERA composite, while INP and OUT contribute much more effectively to it.

[8] *Note: the composite is computed using min-max normalization and arithmetic average with equal weights.*

This confirms that the MAK dimension and its underlying indicators require revision as all three domains should ideally contribute almost evenly to the overall composite.

From these Figures country specific information can be deduced, such as i) the position of the country with respect to the EU27 average for both the overall composite and each domain, and ii) the position of the country with respect to the regression line, which is helpful to identify weak and strong points of performance in each domain.

We have carried out a global sensitivity analysis[9] to appreciate the relative importance of the domains for the overall composite in terms of the so-called first order sensitivity indices (S_i). Such indices vary within the range (0,1). Their values indicate how important each domain is. The results (see Table 7) confirm that domain MAK is five to ten times less important than the other two, which provide about the same amount of information to the overall composite. This occurs for both years *begin Lisbon* and *begin EU-2020*.

Table 7: Results of the sensitivity analysis (S_i mean values)

	Begin Lisbon		***Begin EU-2020***	
	Min-Max normalization	**Z-scores normalization**	**Min-Max normalization**	**Z-scores normalization**
ERA Index vs.				
INP	0.76	0.73	0.78	0.78
MAK	0.06	0.10	0.20	0.18
OUT	0.69	0.76	0.82	0.84
INP domain vs.				
INP1	0.82	0.84	0.74	0.78
INP3	0.88	0.87	0.88	0.86
INP4	0.82	0.75	0.91	0.89
MAK domain vs.				
MAK1	0.66	0.75	0.57	0.67
MAK2	0.46	0.48	0.12	0.12
MAK3	0.33	0.35	0.49	0.51
MAK4	0.20	0.20	0.33	0.28
MAK5	0.35	0.35	0.10	0.08
OUT domain vs.				
OUT1	0.79	0.75	0.72	0.71
OUT2	0.55	0.58	0.74	0.80
OUT3	0.66	0.65	0.45	0.44
OUT4	0.21	0.24	0.13	0.13
OUT5	0.68	0.70	0.34	0.38
OUT7	0.16	0.15	0.22	0.22
OUT8	0.74	0.75	0.74	0.72
OUT9	0.07	0.08	0.08	0.08
OUT10	0.18	0.19	0.24	0.25
OUT11	0.54	0.55	0.59	0.60

We have repeated the same sensitivity analysis at the domain level, for each domain against its underlying indicators (see scatterplots in ANNEX II). The domain INP behaves well, while domain MAK is problematic given its rather highly varying set of sensitivity indices, ranging from 0.57 for indicator MAK1 to 0.10 for indicator MAK5 at *begin EU-2020*. But domain OUT is even more problematic with two, possibly 3 indicators whose importance is too small compared to the others.

[9] The sensitivity indices of the first order $S_i=V[E(Y|X_i)]/V(Y)$ were computed from the $E(Y|X_i)$ curve, obtained by kernel regression of the original data points after Gasser *et al.*, (1991). S_i has been computed by weighted averaging of the regression curve. Instead of a single estimate based on the 41 points available we have boot-strapped the points for the computation of $E(Y|X_i)$ using as many replicas as the sample size (41) and computed S_i mean and standard deviation. The resulting average S_i can be taken as a robust measure of importance.

Clearly, R&D expenditures (the INP indicators), excellence of the Science and Technology Base, and productivity of the economy (from the OUT domain indicators) stand out as the main contributors to the final ERA scores, while knowledge, human resources and financial flows (the MAK indicators), as well as patenting in Grand Challenges matter the least. This problem confirms that the framework applied for the composite needs to be revised.

Country Dynamics

Figures 6, 7 and 8 show again the scatter-plots of the ERA composite indicator[10] against each domain of the framework, with starting year and ending year connected by an arrow to show the changes in country performance with time on a single graph. Note that meaningful comparisons can be made over time, since monetary values were computed at constant price levels, and indicators were normalized with both years in conjunction.

In Figure 6, we notice that most of the arrows have direction towards an increase of INP scores, although a small set of countries (i.e. Sweden, Luxembourg, Belgium, Bulgaria and Turkey) shows a slight negative growth. This is not a good sign, as it means that the overall inputs to build the ERA have diminished with time. Nonetheless, such countries (except Bulgaria) show positive growth for the overall ERA performance.

In Figure 7, the trends are more confused, with MAK scores pointing to both positive and negative directions of change. However, the majority of the countries have positive trend for the domain MAK which is in line with the change in the overall ERA performance.

In Figure 8, all countries except Ireland and Cyprus have positive direction of change for domain OUT, with the top ERA performing countries (see cluster on the right of the picture) having on average small growth for the OUT domain and the least ERA performing countries (see cluster on the left) showing larger growth.

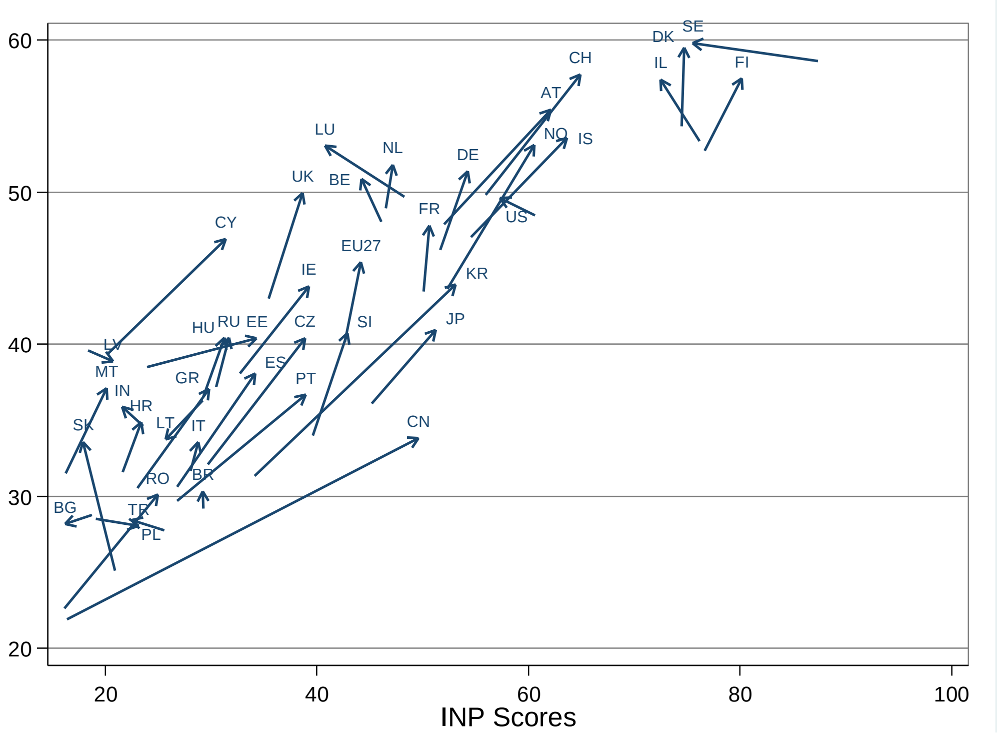

Figure 6: Changes in overall ERA composite scores against changes in INP domain composite scores at *begin Lisbon* and *begin EU-2020* time points, for the ERA countries.

[10] *Note: the composite is computed using min-max normalization and arithmetic average with equal weights.*

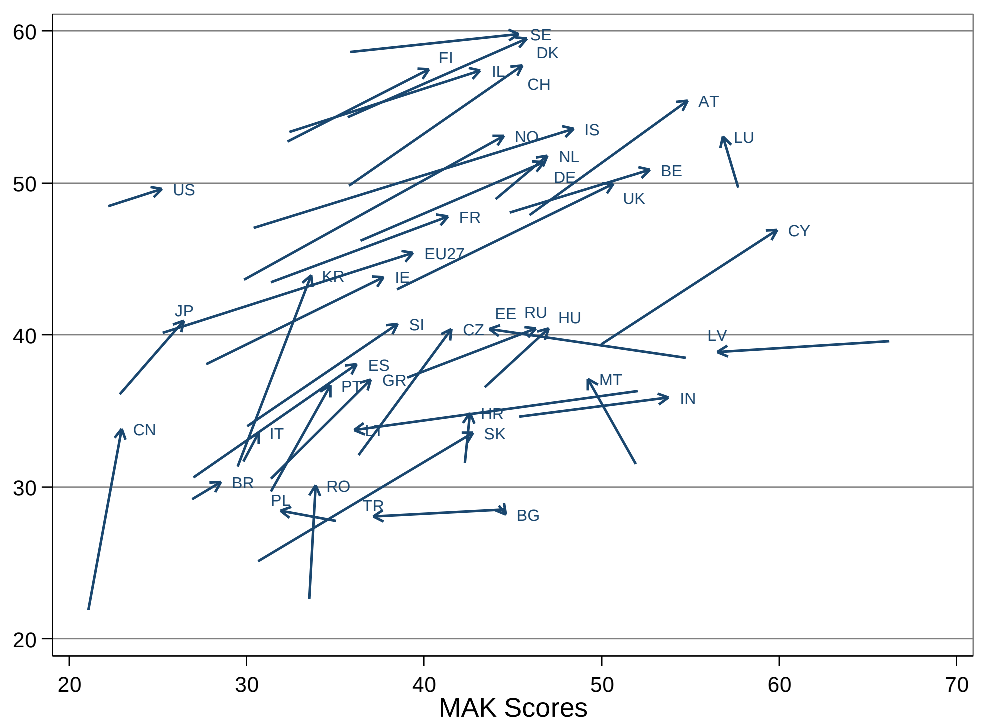

Figure 7: Changes in overall ERA composite scores against changes in MAK domain composite scores at *begin Lisbon* and *begin EU-2020* time points, for the ERA countries.

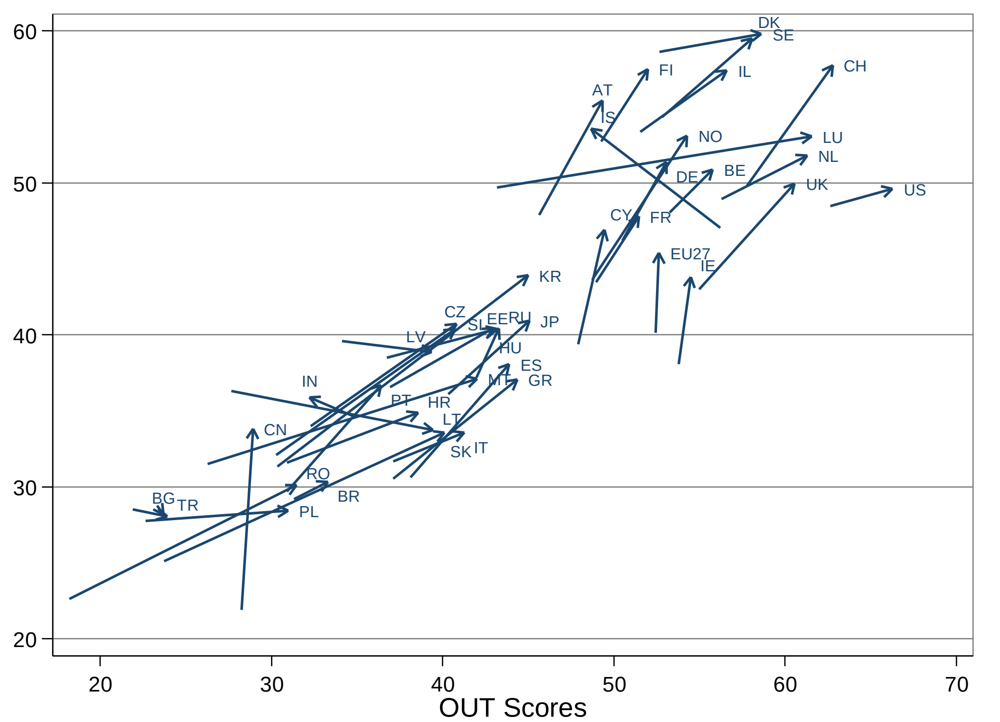

Figure 8: Changes in overall ERA composite scores against changes in OUT domain composite scores at *begin Lisbon* and *begin EU-2020* time points, for the ERA countries.

Considering the performance growth rates of ERA Countries, almost all of them improved over the period *begin Lisbon* and *begin EU-2020*. Those with the largest growth rate are Slovakia (31%), Romania (30%), Czech Republic (25%), Spain (24%), Portugal (21%) and Norway (21%). However, the performance deteriorated for Bulgaria (-3%), Latvia (-5%), Lithuania (-7%), and Turkey (-4%) over the same timeframe.

The engines of the ERA are countries located in the upper-right quadrant of Figure 9, which have both level and growth above the average. Among these, two are non-EU Member States (Norway and Switzerland). France, Germany and United Kingdom have a similar, or slightly below average, growth rate and perform quite better than the EU average. Note that Italy is the only country of the former EU-15 which has both level and growth below the European average. This makes Italy, together with Turkey and the New Member States (bottom-left quadrant of Figure 9), falling behind the rest of the Countries.

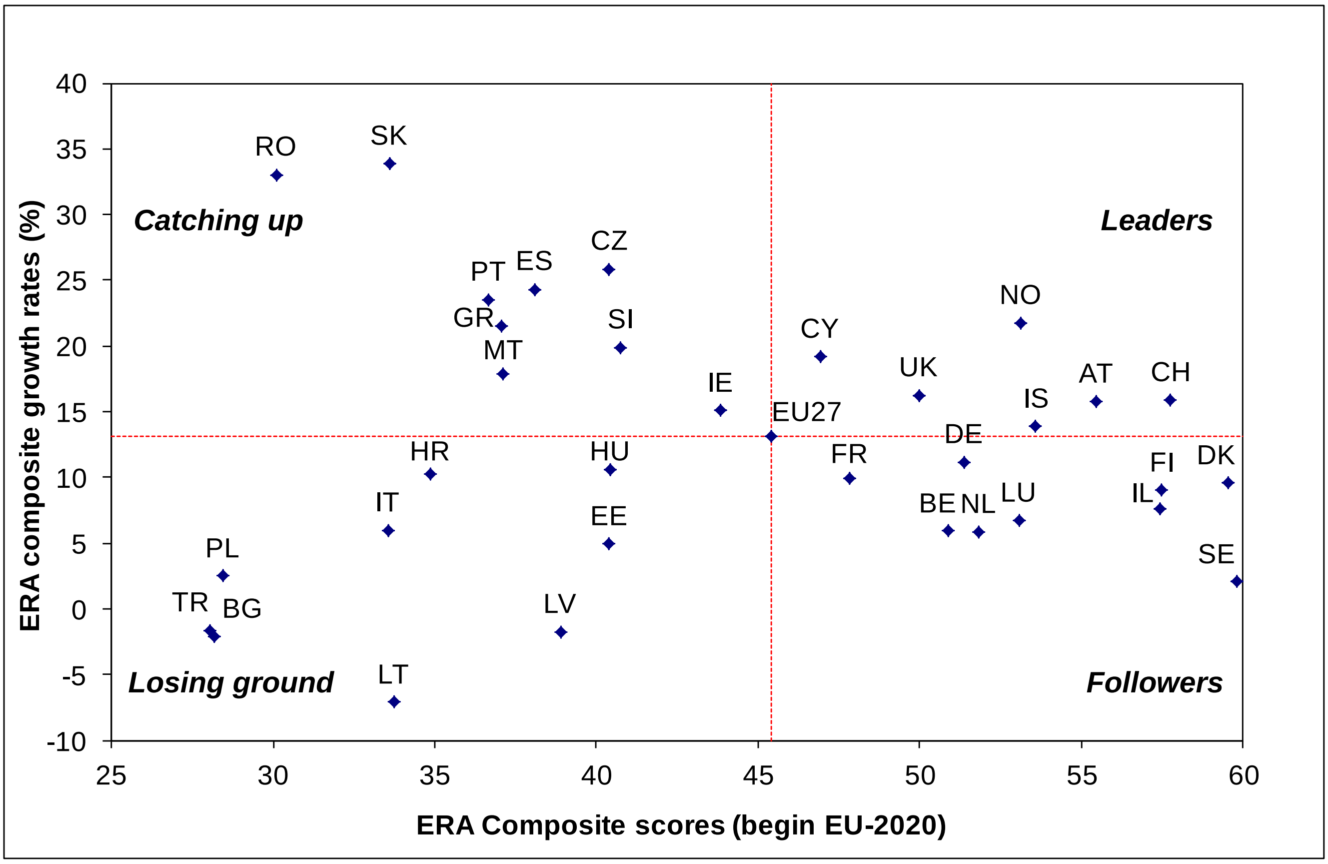

Figure 9: The overall ERA composite growth rates against the corresponding level at *begin EU-2020* for the ERA Countries.

Figure 10 plots OUT composite scores at *begin EU-2020* against INP composite scores at *begin Lisbon*. It is remarkable that low and high performance in the INP domain is associated with future poor and good performance, respectively, in the out OUT domain, although past INP scores are nominally lower than future OUT scores. At the same time, high OUT (near 60) could also be achieved with average past INP scores (i.e. in the case of the United Kingdom, the Netherlands or Luxembourg). This appears to justify the cautionary remark of the ERA Expert group Report that a causal link is not necessary between the INP and OUT domains.

We further explored correlations between the ERA composite scores or its sub-domains and other meaningful indicators such as GDP, and the Summary Innovation Index of the Innovation Union. These should be seen as the result of initial explorations of correlations patterns, and not in any way as explanation of causalities.

In general, a higher GDP per capita is associated with higher ERA composite scores, as shown in Figure 11. In a sense, GDP per capita shows the ability of countries to invest and participate in an integrated European research and innovation system. Nordic countries (except for Norway), together with Israel, Austria and Switzerland perform relatively much better in the ERA composite than their GDP, while countries from Southern Europe, Slovakia, Poland, and especially Italy, may mobilize more resources for the construction of the ERA.

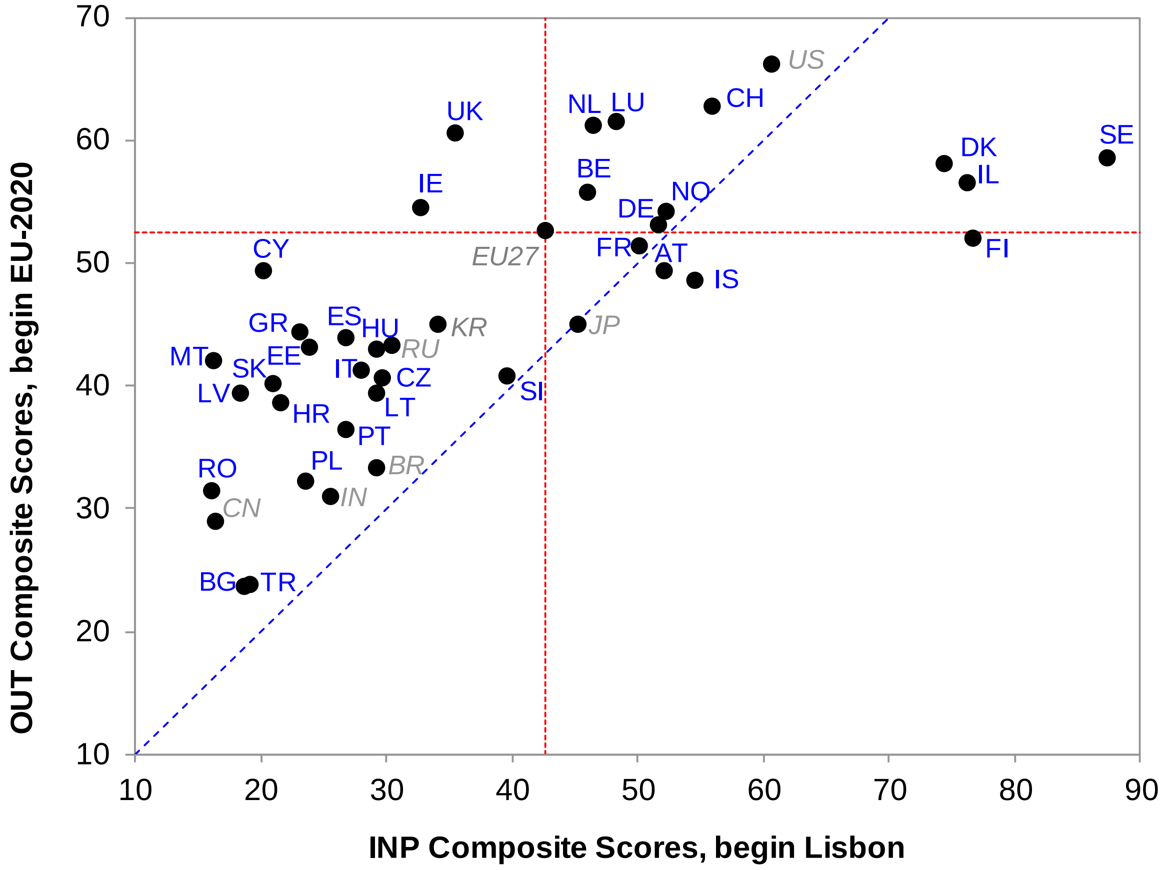

Figure 10: OUT domain scores at *begin EU-2020* against the INP domain scores at *begin Lisbon*. 45° line from the origin depicted in blue.

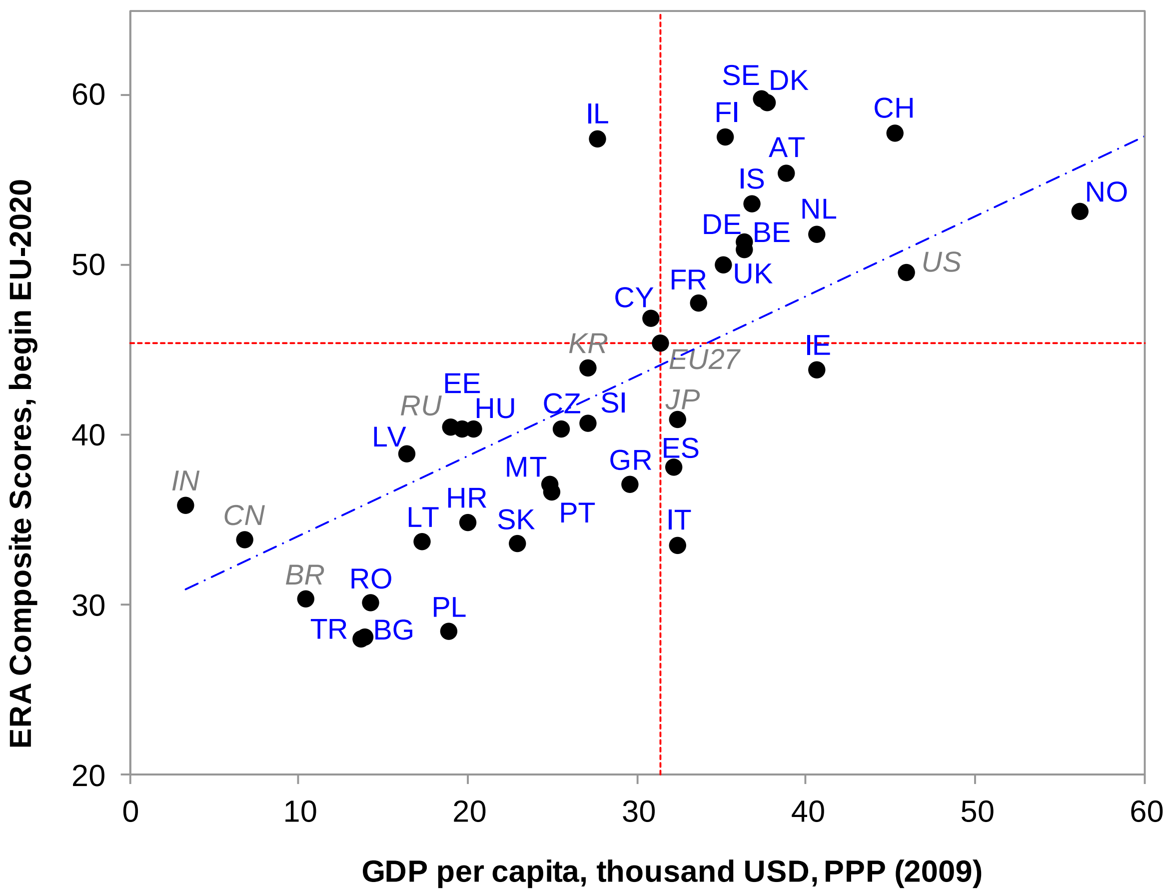

Figure 11: ERA composite scores against the GDP per capita at *begin EU-2020*.

Figure 12 compares country composite scores for the Summary Innovation Index of the Innovation Union Scoreboard 2010[11] with those of ERA. The same group of countries (Sweden, Denmark, Finland and Switzerland) perform well in both indicators, and the same group of countries (mostly the new member states and candidate countries) have low scores on both. Italy, Portugal and Ireland have remarkable lower scores on ERA compared to that of the Innovation Union.

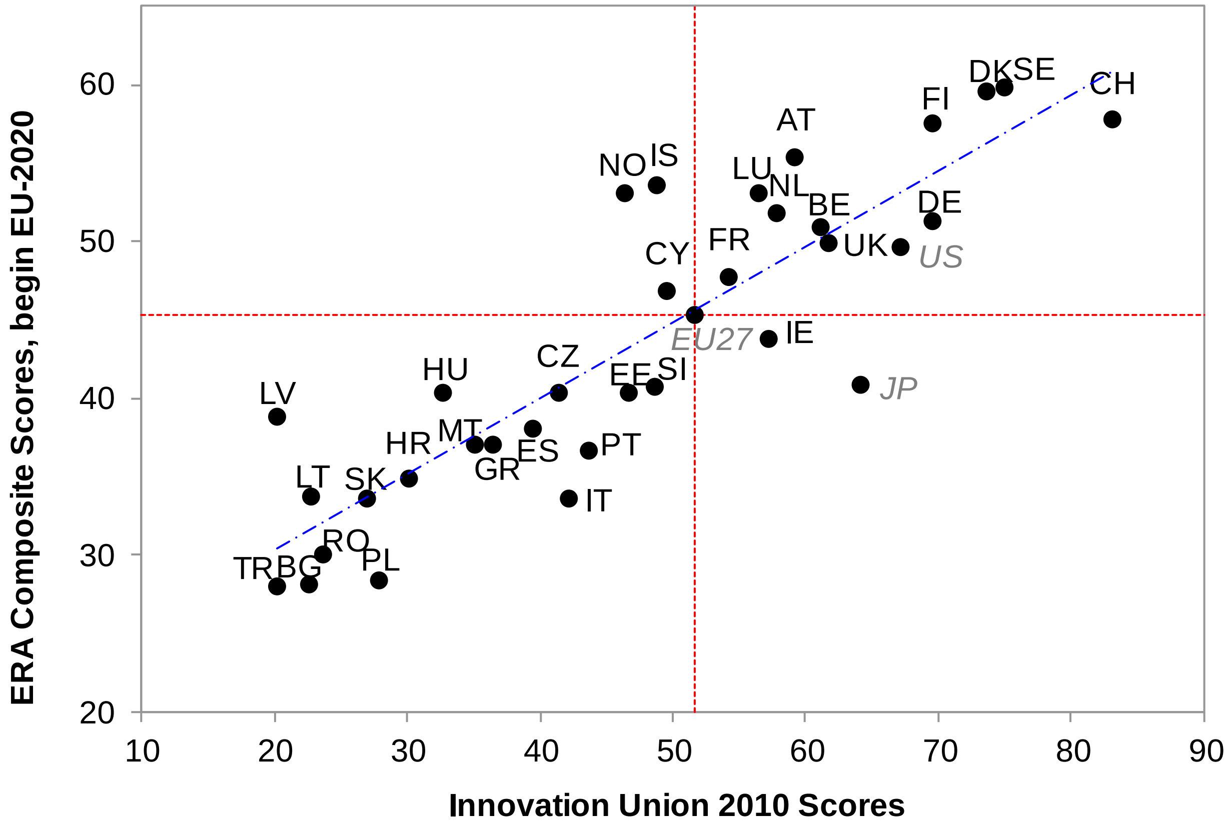

Figure 12: ERA composite scores at *begin EU-2020* against Innovation Union 2010 composite scores

Modified composite indicator: international benchmark

This modified version of the main composite indicator excluded indicators MAK1 and MAK2 with the aim to contrast the aggregate EU27 against other selected international benchmark countries (Brazil, China, India, Japan, Russia, South Korea and the United States). It would have been informative to compare also the ERA aggregate against overseas countries, but key data (interaction and cohesion data) were missing for some ERA countries (Israel and candidate countries). Here, for completeness, ERA Countries performances were also reported, but the benchmark remained incomplete, as it left out the indicators MAK1 and MAK2.
As for the previous composite indicator, we also developed eight different scenarios combining exactly the same alternatives for imputation, normalization and aggregation.

The results for the eight scenarios were also in this case quite similar, so we decided to represent one of them in Figure 12 (the combination min-max with arithmetic average) and all of them in Figure 13 in terms of interval rankings for the four scenarios. In both figures the composite scores and rankings were provided for both time points, *begin Lisbon* and *begin EU-2020*. The composite scores and rankings were also computed for ERA countries for completeness, although the comparisons between ERA countries made less sense because indicators MAK1 and MAK2 were missing.

[11] For details on the index, see the Methodology Report of the Innovation Union Scoreboard 2010: [http://www.proinno-europe.eu/sites/default/files/page/11/IUS_2010_Methodology_report.pdf]

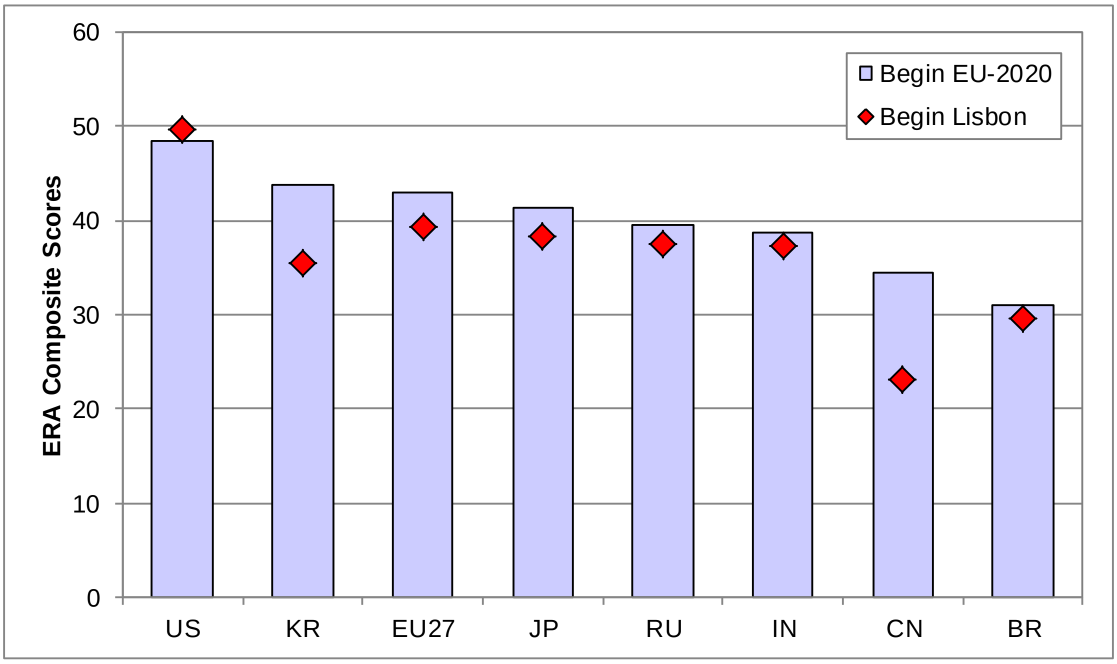

Figure 13: The overall ERA composite scores for Europe and selected countries at two time points.
Note: the composite is computed using min-max normalization and arithmetic average with equal weights and hot-deck imputation.

Looking at Figure 13, we observe that United States has the leadership among the countries of the international benchmark, followed by South Korea, Japan, EU-27, Russia, India, China and Brazil. However, there is no evidence of growth of the US between *begin Lisbon* and *begin EU-2020* whereas all the other countries of the benchmark improved their performance in the same timeframe. Among them, China and Israel are the countries with the highest growth.

Figure 14 shows all four scenarios together in the form of an interval encompassing all eight rankings. The intervals allow us to make a thorough assessment of the performance of the countries across the four scenarios. We note the overlap among the intervals of the EU27, South Korea, Japan, meaning that these countries form a cluster with the same level of ERA performance. The confidence intervals for Russia, India, China and Brazil are rather broad. This is caused by the relatively high share of missing data for these countries, thus the choice of imputation method affects country rankings.

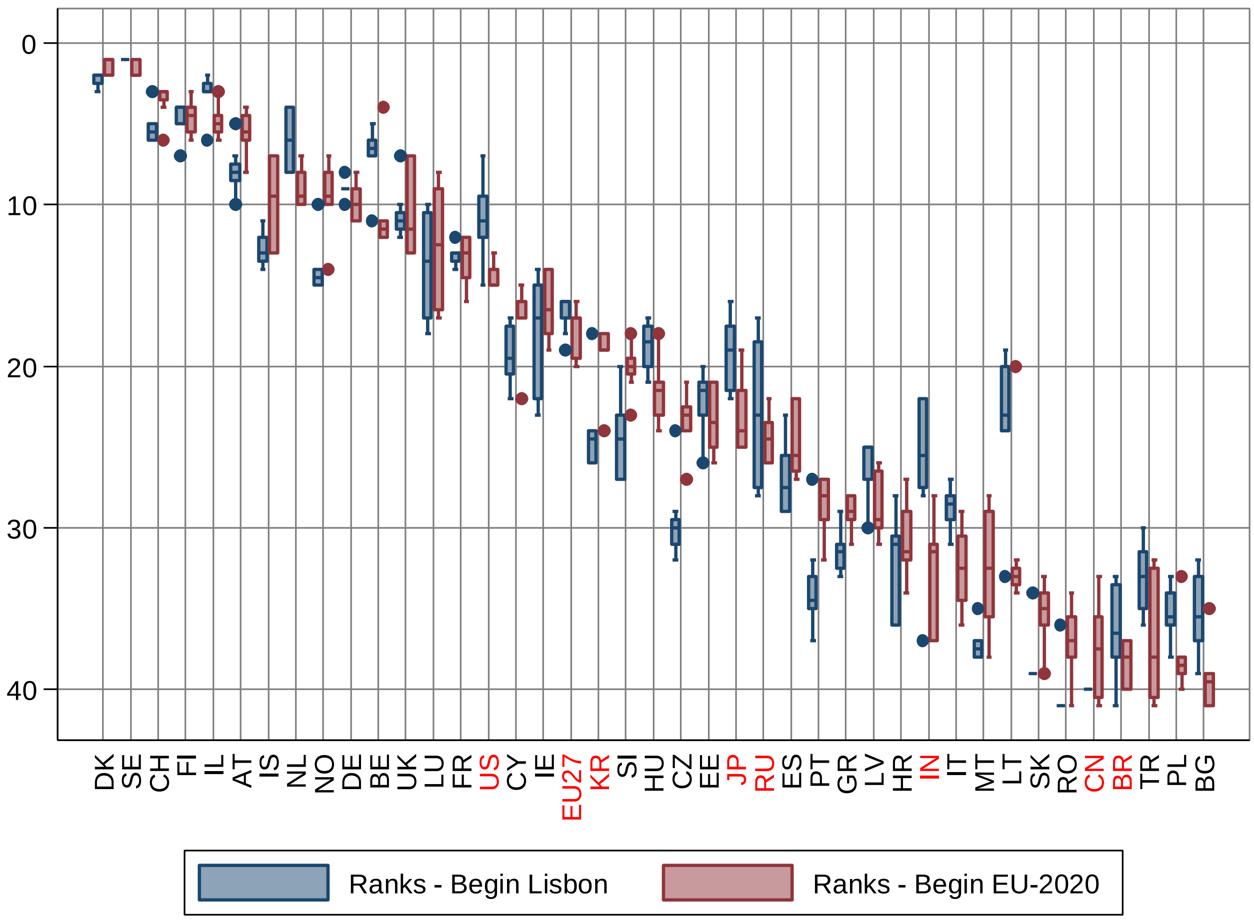

Figure 14: Box plot of ERA composite rankings at *begin Lisbon* and *begin EU-2020* time points, for the international benchmark.

Note: Eight scenarios included are based on min-max and z-scores normalization, arithmetic and geometric aggregation, and hot deck and regression imputation methods

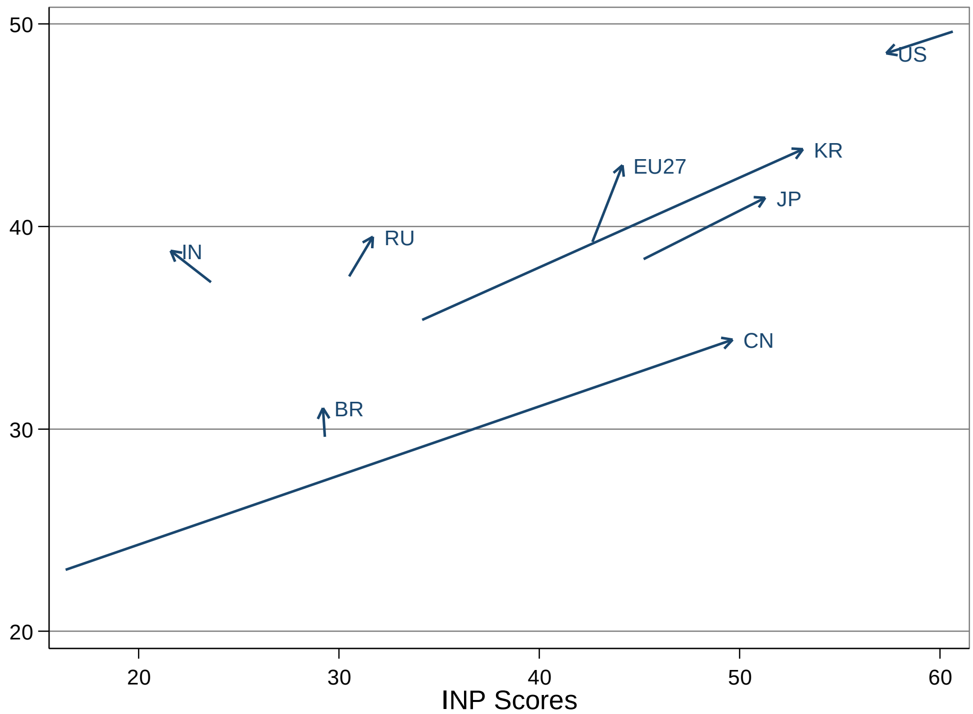

Figure 15: Changes in overall ERA composite scores against changes in INP domain composite scores at *begin Lisbon* and *begin EU-2020* time points, for the international benchmark.

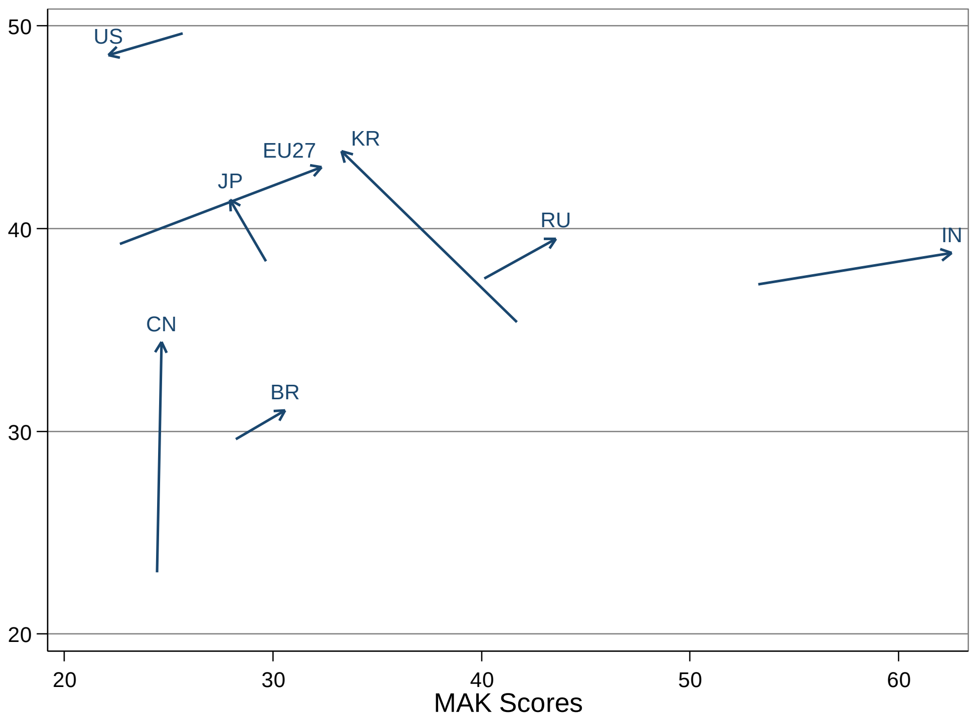

Figure 16: Changes in overall ERA composite scores against changes in MAK domain composite scores at *begin Lisbon* and *begin EU-2020* time points, for the international benchmark.

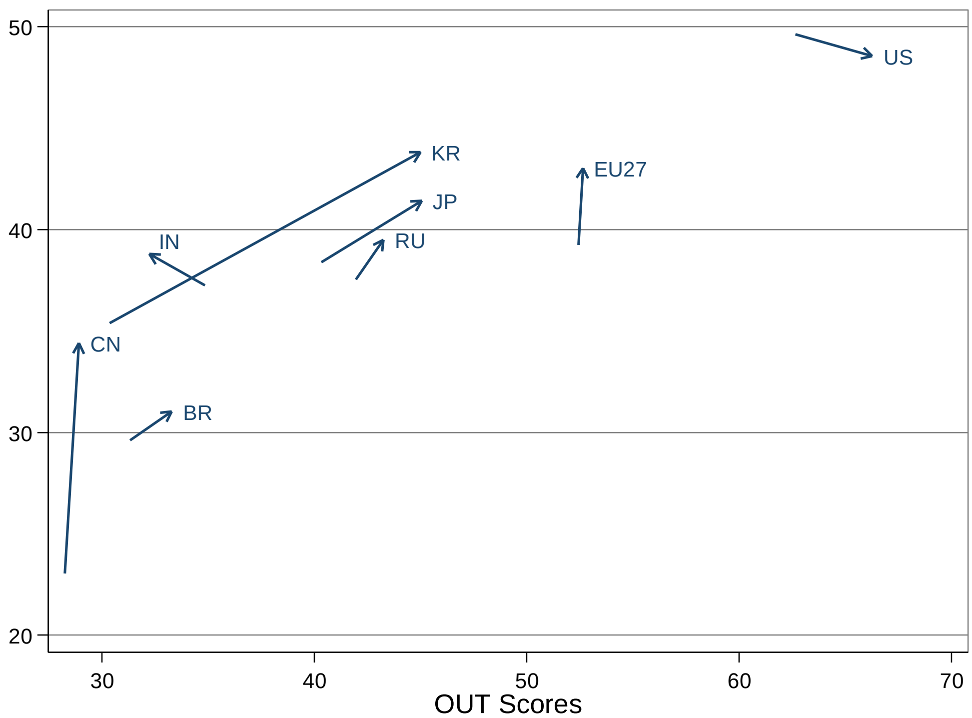

Figure 17: Changes in overall ERA composite scores against changes in OUT domain composite scores at *begin Lisbon* and *begin EU-2020* time points, for the international benchmark.

Figures 15, 16 and 17 show again the scatter-plots of the ERA composite indicator[12] against each domain of the framework, with starting year and ending year connected by an arrow to show the changes in country performance over time on a single graph.

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[12] *Note: the composite is computed using hot deck imputation, min-max normalization and arithmetic average with equal weights.*

In Figure 15 we notice the slight decrease in INP score for both the US, Israel and India, whilst China doubled its score and EU-27 slightly increased its own. A different scenario is depicted in Figure 16 where India and Israel have considerably high score and growth in MAK, contrarily to US and China which start from and remain at a very low score. South Korea has also a large decrease in MAK score whilst its overall composite score increases.

The outcome of the ERA process is depicted in Figure 17 with the EU-27 and China stagnating in the timeframe considered while US and Japan slightly improving. On the other hand, Brazil shows a considerable improvement.

Conclusions

This report is the deliverable of the first work package of the feasibility study entitled: 'ERA monitoring: Composite Indicators measuring the progress in the construction and integration of a European Research Area', financed by DG RTD.

For this deliverable we developed one composite indicator to measure progress in the construction and integration of a European Research Area (ERA). This composite indicator benchmarks the performance of European Countries towards the implementation of the ERA and uses all available indicators from the list proposed by the Expert Group as Headline Indicators. A modified version of the main composite indicator benchmarks the performance of the European research and innovation system with selected countries (US, JP, CN, BR, IN, KR, RU). The indicators required for this study and the theoretical framework were drawn and adapted using the headline indicators proposed by the expert group report[13] on 'ERA indicators and monitoring' 2009 EUR 24171 EN.

Considering the absence of data for some indicators, the team recommends data providers to take the necessary steps to improve data availability, especially for the indicators "INP2: European Integration of Research Systems", "MAK4: Mobility of researchers and research careers", "MAK6: Pan-European research infrastructures", "OUT6: Firm Dynamics - Structural Change", which were left out from the analysis. Due to the lack of data we were forced to use two fundamentally different imputation methods. We found that the choice of the method slightly influences country rankings, particularly in the lower segments.

The study tested the framework originally proposed by the Expert Group, and found, on the basis of the available data, the multivariate analysis and the sensitivity analysis, that the present structure makes the quantification of the various aspects of the ERA quite loose and approximate. The team recommends, for the follow-up of the project, to investigate a more structured framework for the ERA, expanding the number of dimensions and to identify and calculate some extra indicators to populate the framework in more detail, for instance, based on results of a PCA. The need for revision applies mostly to the domain MAK in which its indicators should ideally be replaced by framework dimensions representing joint knowledge production in the science base,[14] mobility, infrastructures and financial flows.

Given the weak contribution of the MAK domain to the definition of the overall composite, we thought to test an alternative framework in which we consider only two domains, INP and OUT, whereas indicators MAK1, MAK2 and MAK5 are removed because they have negative correlation with other indicators in the other two domains, and the rest of them (MAK3 and MAK4) is moved to the OUT domain. Conceptually, this means that if the process of making ERA interactions cannot be measured directly, proxies on input and output are used instead. By repeating the multi-variate statistical analysis we find a practically unaltered situation with a too high number of components that are needed to describe the OUT domain. This confirms our belief that a few sub-domains for the OUT domain need to be identified.

[13] The full report is available at: http://ec.europa.eu/research/era/pdf/era_indicators&monitoring.pdf
[14] We thank Robert Tijssen for proposing this term that replaces the word 'publications' in a draft version of this report.

Concerning the MAK domain, we believe that indicators need to be redefined. For instance, co-publications within the EU are not a guarantee of excellence, which is reflected by the very low correlation between MAK1 and OUT1. This quality could be included in MAK1 by limiting the total number of co-publications to those in the top 10%. We also observed that the indicator MAK3 (co-publications with non-EU actors) is a more suitable indicator than MAK1 (co-publications with EU-members) for it includes the aspects of openness and research excellence, and seems to be more important for a better functioning research and innovation system.

In sum, we found that on the one hand, R&D expenditures, excellence of the Science and Technology Base, and productivity of the economy are primarily reflected in the final ERA scores. On the other hand, the indicator is not sensitive to variance in international flows of knowledge, human resources and finance, as well as patenting in Grand Challenges. Conceptually ERA is composed of infrastructure and interacting actors, so it is problematic to find that interactions as defined in the present framework are of less importance. A future study taking into account the recommended modifications could help us to refine these conclusions. For the reasons given above, we recommend to consider the results obtained in this feasibility study as preliminary.

Acknowledgements

The authors would like to thank their colleagues Michela Nardo, Michaela Saisana, Andrea Saltelli, Johan Stierna and Herman van der Plas for their comments to preliminary versions of the report. In particular, we acknowledge Andrea Saltelli for his help in executing the sensitivity analysis for the overall composite and the single dimensions.

Comments from the Experts of the Advisory Group to the ERA Monitoring Project

An Advisory Group was set up for the purpose of providing a critical review of all the draft reports produced by JRC in the framework of the ERA Monitoring project. The feedbacks from the Advisory Group are presented hereafter, in alphabetical order. These comments are meant to be taken into account for the development of the full-fledged composite indicators.

Isidro Aguillo

The Cybermetrics Lab, IPP-CCHS-CSIC, Madrid

OUT1 and OUT2 are using different sources as the database analyzed by Science Metrix data is Scopus/Elsevier while CWTS is deriving the Leiden Ranking from ISI Thomson citation databases. I think it is an inconsistent approach and I think there is also an alternative feasibility option: Scimago group data that has (Open Access) country data and institutions ranking derived both from Scopus.

The correlation between the size of the ranking, the GDP of the countries and the total number of countries represented in the ranking is highly positive. That means that is important to use a ranking of universities with more than 250 universities in order to avoid false zeros for many EU countries. Obviously the ratio you will obtain for some countries will be very low but not zero. A point system will be needed: 10 points for each university in Top 100, 8 for 101-200 ranks, 6 for 201-300, 4 for 301-400 and 2 for 401-500. The Scimago ranking has even more coverage.

In Europe research excellence is not only present in the universities, as there is a lot of "national Councils" (CNRS, Max Planck, CNR, CSIC, etc.) and similar independent research bodies with a very important production. The Scimago ranking consists of both university and non-university institutions.

EUMIDA project has collected a lot of data for EU universities, perhaps some indicators can be derived from that source.

South Africa is now part of the BRICS. Perhaps it will interesting to add Mexico, a member of OECD and the most probable candidate to be added to BRICS in the future.

Of course, some webometrics indicators should be also be considered. For example, see Park, Han Woo, Barnett, G. and Chung C.J. (2011) “Structural changes in the 2003–2009 global hyperlink network”, *Global Networks* Vol.11, No. 4. pp.522–42.

Rémi Barré

Professor of Science Policy, CNAM, France

The report elaborates a detailed framework for building a composite indicator measuring the progress of the ERA. Starting from the results of the expert group on “ERA indicators and monitoring”, it proposes a new structure of indicators, classified in three categories (input, ERA making and outcomes, labelled INP, MAK and OUT, 18 in total). They propose various schemes of aggregation, combining the alternative ways to do so, showing the relative stability of the results they provide.

An important work has been done regarding the availability of these indicators, for the member and associated states and for international benchmark countries. Their value has been measured at two dates and only a very few remain undocumented.
A full experimentation of the computation and analysis of the indicators and of their composite has been performed which shows their overall relevance and richness of the proposed framework and indicators for addressing the complex issues associated with the making of the ERA (analysis per

category, per country, at two dates, plotting the composite scores of the countries against a variety of parameters…).

Having laid the basis for the composite indicator and shown its operational feasibility, the authors realise a thorough critical analysis of their framework. They use multivariate analysis for assessing the structure (correlations) among the indicators regarding each of the three categories. This reveals the correlation between three of the four input indicators among them and with some of the outcome indicators, which carry most of the variance. The ERA making category along with (probably) the fourth input indicator (public funds in transnationally coordinated research) refer to other dimensions, being loosely correlated among them and with the above mentioned indicators. These results lead the authors to question the most appropriate classification and definition of indicators, calling for further investigation.

This work is systematic, thorough and solidly grounded. It is also original in its conceptual framework.

A few points would deserve particular attention in the future, most of them already identified by the authors:

- the list of indicators pertaining to the three categories, with the issue of the number of indicators to be selected for each dimension revealed by the multivariate analysis,
- the ERA making category deserves further work, but its specificity ought to be recognised: it does not deal directly with short term excellence of individual countries, but with overall excellence in the longer term,
- the adequate adjustment of that list when making comparisons with non-EU countries,
- the cautiousness in interpretation of the position and evolution of the smallest states in the EU, which data and score may be very unstable,
- the proper use of a composite indicator, where the contribution of each individual indicator to the aggregate result (score) should be interpreted with great care since (a) we deal basically with correlations, not causalities and (b) the form of the composite is one among many possibilities giving similar results (any indicator can be replaced by one correlated to it), thus questioning the analysis in terms of the impact of a particular indicator on the overall score,
- the uncertainty and sensitivity analysis are a strong point of the report and should deserve the same level of attention in the future work.

This WP1 fulfils its aims in the sense that it provides a complete ‘run’ withy a plausible set of indicators, thus allowing for a critical analysis both in conceptual – methodological terms, but also in view of the kinds of results one can get and of the kinds of analysis and interpretations which are made possible. From there, the authors are able to provide the relevant perspectives for further work.

Matthieu Delescluse

DG RTD, European Commission

INP3 is highly correlated with INP1 and INP4 (INP3 = INP1 + INP4 - expenditure on tertiary education) and does not add much information. It could therefore be removed. It might be clearer to have GOVERD+HERD, Expenditure on tertiary education, and BERD as three separate INP indicators. INP1 can then be obtained by adding the first two indicators and INP3 by adding the first and third (PNP is negligible in most cases).

The wording of MAK1, MAK2 and MAK3 should be harmonized since they are all built the same way:
Number of cross-border co-publications with EU countries (MAK2: with the 10 lowest R&D intensive EU countries) (MAK3: with non-EU countries) / Total number of publications

EU could be replaced by ERA in these indicators. DG RTD has the data from its service contract with Science Metrix.

The equivalent of MAK1 and MAK3 for co-invented EPO patents could be added to the list of MAK indicators. The data are produced by Eurostat. In this data, the distinction is between EU/non-EU, not between ERA/non-ERA.

The Average Relative Citations (ARC) of Science Metrix could be added in the list of OUT indicators, together with the top-10% most cited publications indicator.

OUT2 poses several problems. Most countries will be at 0. It is discretionary, so that growth rates are meaningless and the position of country with that indicator can in theory change dramatically just with one unit more or one unit less in the ranking for that country. The indicator treats similarly the top and the bottom of the ranking.

For OUT4, the Knowledge Intensive Activities taxonomy that DG RTD has developed with Eurostat could be used. The following indicator is used in the Innovation Union Scoreboard and could be used here for the sake of consistency:
Employment in business KIA as a % of total business employment

For OUT7, BERD by affiliates of foreign companies is widely available and is in my opinion better than BERD financed by abroad regarding attractiveness. Much of the R&D of foreign affiliates (FA) is not funded by abroad. The presence of R&D activities by foreign firms is therefore better captured by BERD by FA.
In addition, DG RTD does have the distinction EU (European) vs non-EU (non-European) origin of BERD by FA in its current study on internationalisation of business R&D. However, it is true that much of this geographical info may come from the National Statistical Institutes (contacted by DG RTD's contractor for the purpose of the study) rather than from Eurostat/OECD databases. It might therefore become more difficult in the future to keep the European/non-European distinction.

In addition, it would make sense to normalize this indicator. A suggestion would be:
(BERD by FA / BERD) / (Value Added by FA / total Value Added)
This indicator is meant to inform about the relative attractiveness of R&D vs production activities in a country.

I would add an OUT indicator on "PCT patent applications per billion GDP" (by inventors' country of residence) to inform on the general level of patenting activity, beyond societal challenges.

Science Metrix has built a composite indicator of scientific performance on their set of individual bibliometric indicators. A description of this indicator can be provided.

Emanuela Reale

Senior Researcher, CERIS-CNR, Italy

The deliverable developed a theoretical framework accurate, reliable and in line with the aim of the WP. The work makes an extensive use of the results proposed by the Expert Group Report on ERA Indicators and Monitoring, trying to put them into action through the construction of composite indicators on the progress of ERA.
The exploitation of eighteen headline indicators, grouped into three dimensions (INP, MAK, OUT), shows that the supposed availability and feasibility of the proposed indicators is not a rule, and some strong constraints affect the selected measures.
First of all, as the INP group is concerned, data are generally available, but an important exception can be outlined, because the most important item is lacking (INP 2 Share of national public funds to transnational coordinated research). In this respect, some results are now available from the data collection developed within the JOREP Project, which set up a database on Joint Programmes within eleven European countries. Nevertheless this exercise is still too limited as to the country coverage for being a base for the INP 2 indicator, nor input can come from the exploitation of the GBAORD

data, since the experience done in JOREP showed that GBAORD is useless as source for funding data on transnational R&D programmes.
As a second remark, MAK dimension is very relevant for capturing the progress toward the ERA in different countries; unfortunately this emerged as the weakest dimension among those considered in the study. Publications and co-publications capture only a part of the cooperation and cohesion, also because large part of SSH are excluded and the data are biased for some countries; research infrastructures data cannot be used, and the source of indicators for mobility cover only a limited period in time (2004-2007).
On the OUT side, indicators on mobilising R&D (OUT 9 and 10) do not include publications, a relevant data for representing the R&D output, especially for the public sector of research; long time series were not available for OUT11.
In sum, lack of data impact on the results of the sensitivity analysis, with the domains of MAK and OUT being problematic; the same occur when MAK is used for country dynamic.
Given these restrictions, the conceptual framework needs a better design of how to represent the process and a deep investigation on indicators. As to the former, distinguishing between construction of ERA (which refer to coordination and collaboration) and the process of integration of actors (policy actors and R&D performers) would be useful in order to use the most appropriate indicators. This implies in some case to elaborate beyond the proposal of the Expert Group Report on ERA Indicators and Monitoring. As to the investigation on indicators, at the moment the composite indicators are useful to understand the state of the art of the ERA countries and to benchmark with the non-ERA ones, but less useful to show progress and processes (country dynamics and scenarios are not really meaningful).

Robert Tijssen

Professor of Science and Innovation Studies, Leiden University, The Netherlands

The cross-sectoral cooperation ('industry-university cooperation' on page 7) is mentioned at several places within the report, while no reference is made to the fact that an existing EC-performance indicator covers this type of cooperation. It is included in the Innovation Union Scoreboard 2011, as well as in its predecessor series of European Innovation Scoreboards,
The indicator was developed by me in the mid-1990s, and I'd be happy to give more details on its conceptual background and technical ins and outs if needed.

My own studies show that this indicator is positively correlated to one of the pre-selected 'ERA headline' indicators, i.e. 'share of publicly-performed research funded by business' (indicator H6). Nonetheless, I wouldn't be surprised if this new bibliometric indicator (based on counts of joint research publications) adds significant analytical value, robustness and relevance to the MAK subcategory of the ERA composite indicator. This indicator is powerful in that it allows a dual perspective of public-private cooperation: the statistics can be calculated for the country in which the industrial partner is located ('knowledge users'), but also the country in which the collaborating partner from the public sector is based ('knowledge producers'). Moreover, the data can be broken down into intra-EU cooperation ('ERA making' dimension; MAK category) and/or collaboration with partners outside the EU ('ERA effects' dimension; OUT category).

The problematic terminology applies to the bibliometric indicators assigned to the OUT-group (OUT1 and OUT2), which are now referred to as 'excellence of the S&T base', but actually reflect the presence of high-quality research capacity in national science systems, broken down into 'High impact science' (OUT1), and 'World class academic research capacity' (OUT2).

Some countries show trajectories that are contrary to the general (upward) trend depicted in Graphs 6, 7 and 8 (notably BG, TR, PL, LU, US, SE, LV). In some cases this outcome seems counter-intuitive and is therefore likely to attract a lot of attention among readers and users (especially from those respective countries). You need to address this issue and examine - in detail – which indicators are responsible for these results, and whether or not specific weaknesses in the data (biases, unjustified imputations, etc.) underlying these indicators are affecting these divergent dynamics.

A concerned effort should be made to verify whether all currently available and useful indicators (i.e. high-quality and appropriate indicators) have indeed been used to compile this composite indicator. As indicated in the above item (on public-private cooperation) some interesting candidates for additional indicators are not included. And there might be others that were also overlooked or initially discarded, but may still be worth considering.
The next stage of this project should devote sufficient time and resources on making a comprehensive inventory of new indicators the recent RDI indicator reports (produced by national or international agencies) to identify these candidates, examine their technical properties and general availability, and assess their analytical added value for an ERA composite indicator as compared to the current set of constituent indicators.

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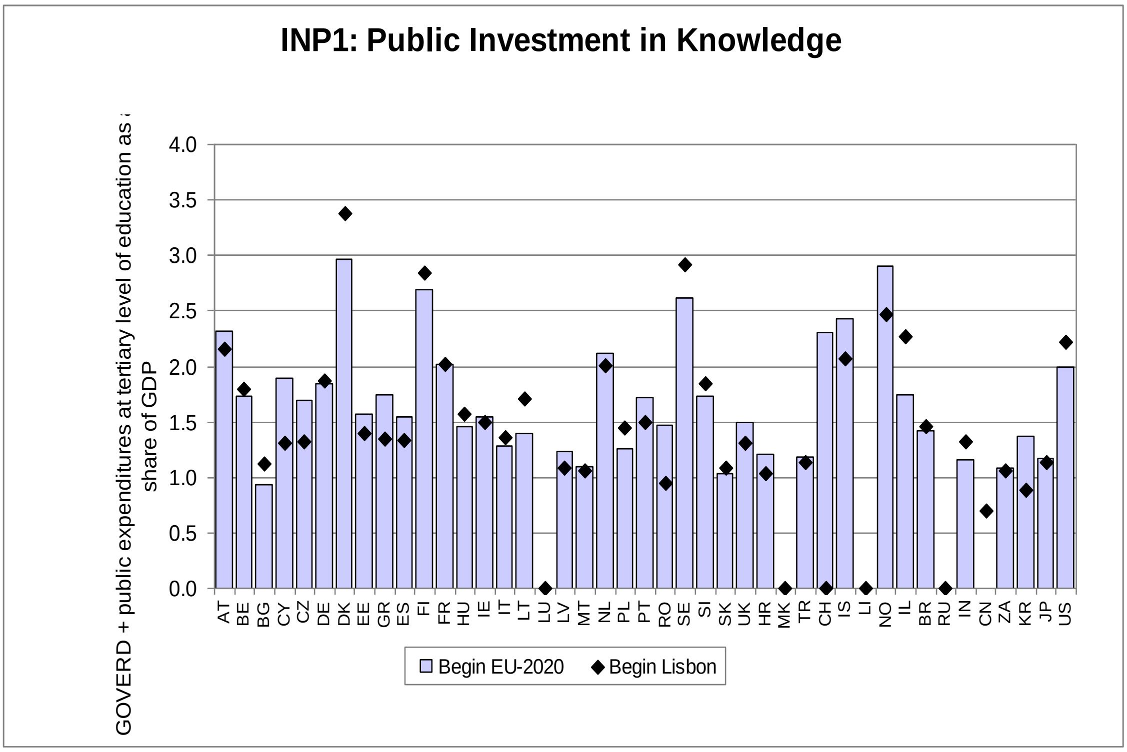
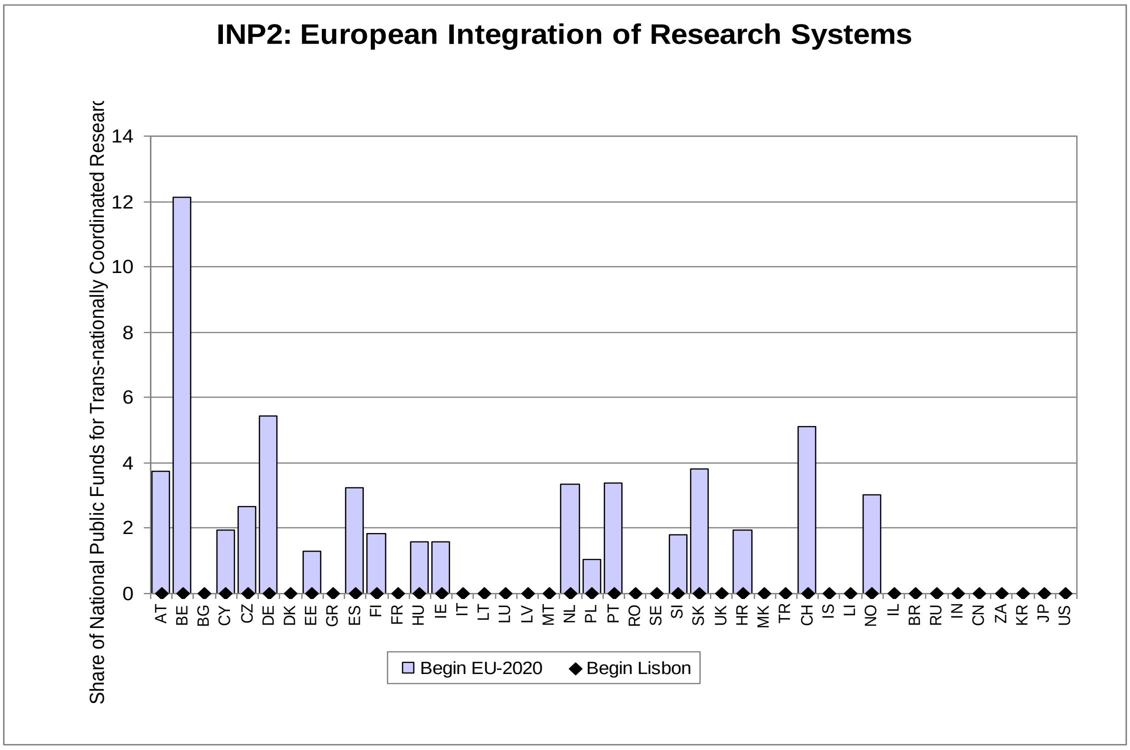
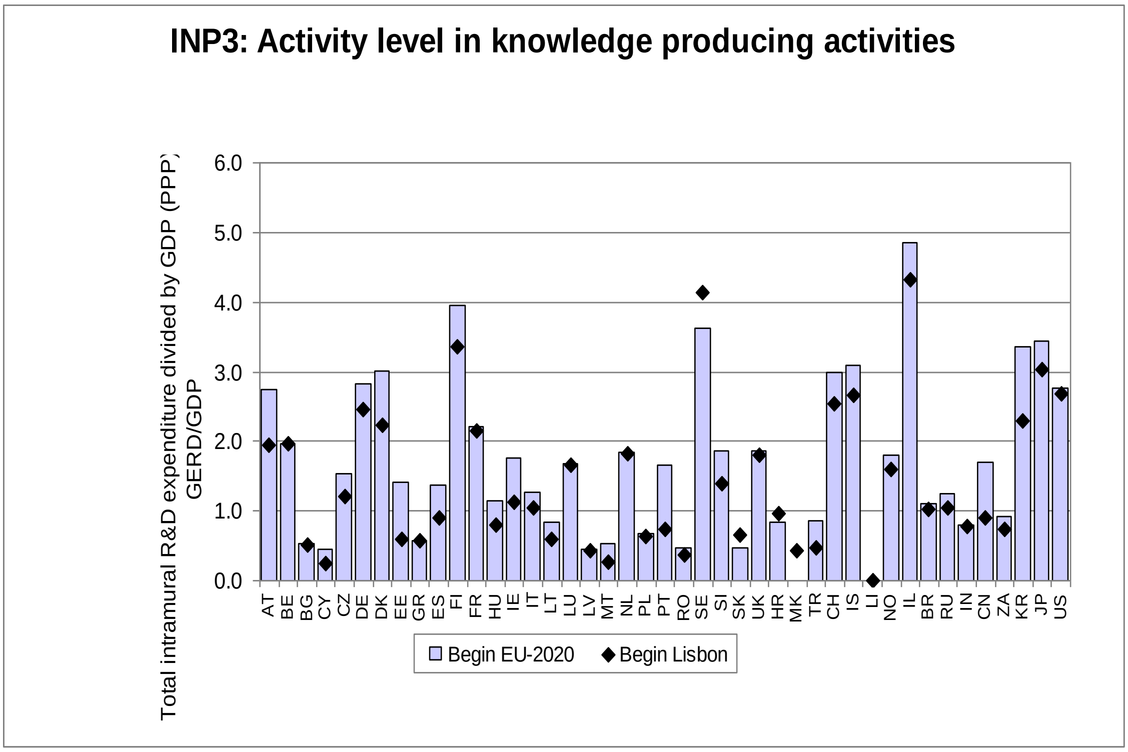
ANNEX I

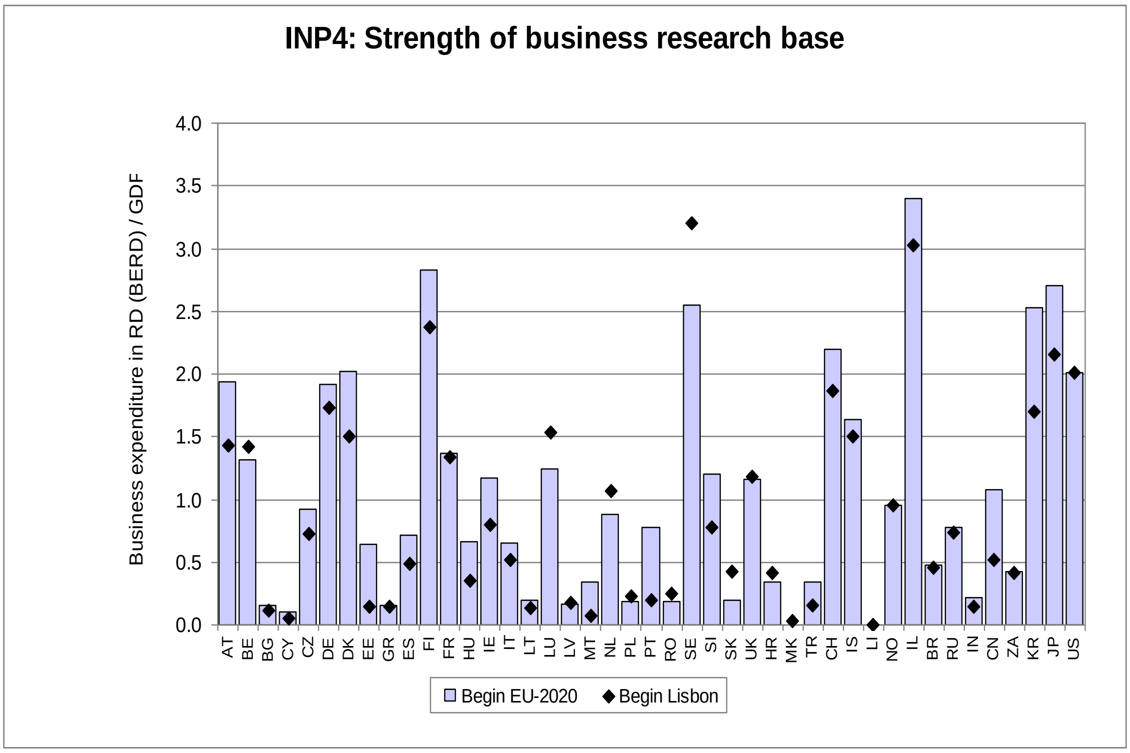
Indicators by country at *begin Lisbon* and *begin EU-2020*
(Raw data, before imputation)



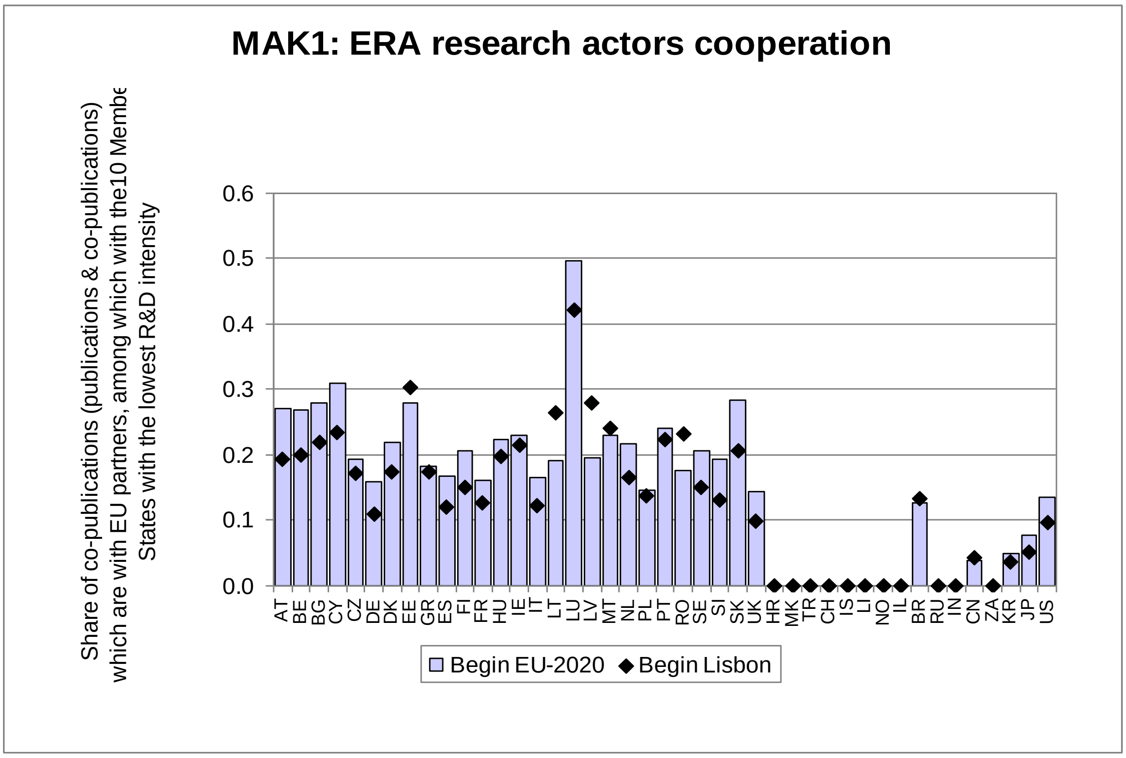


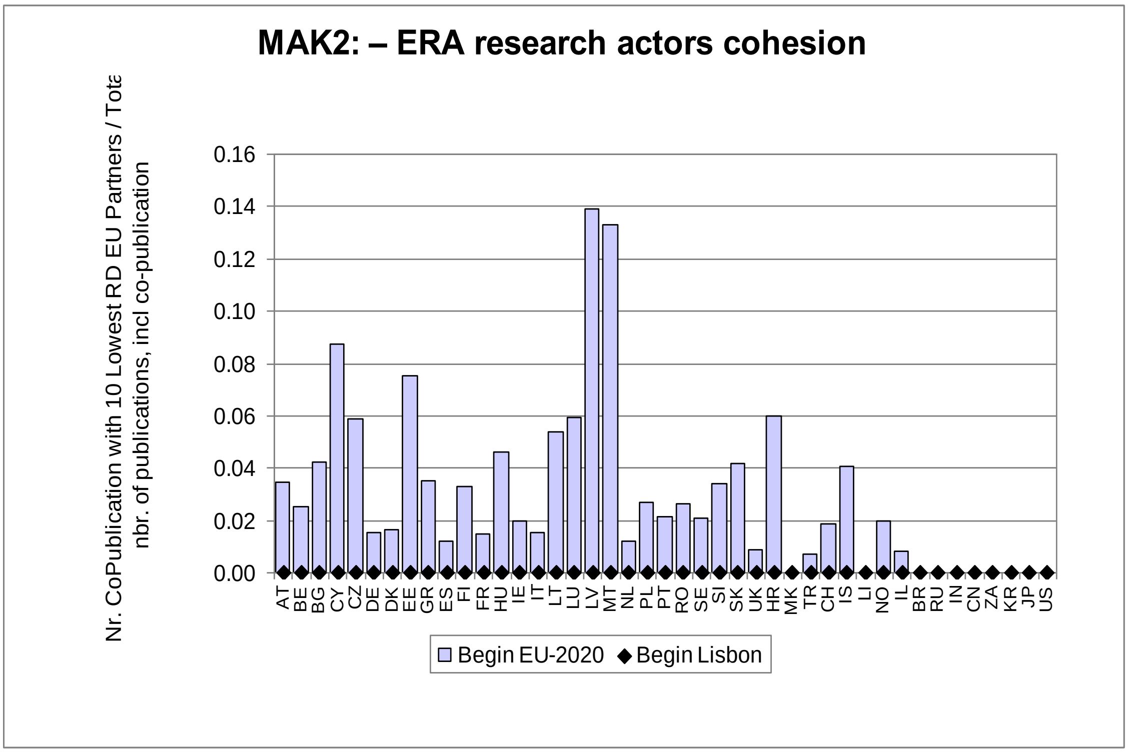


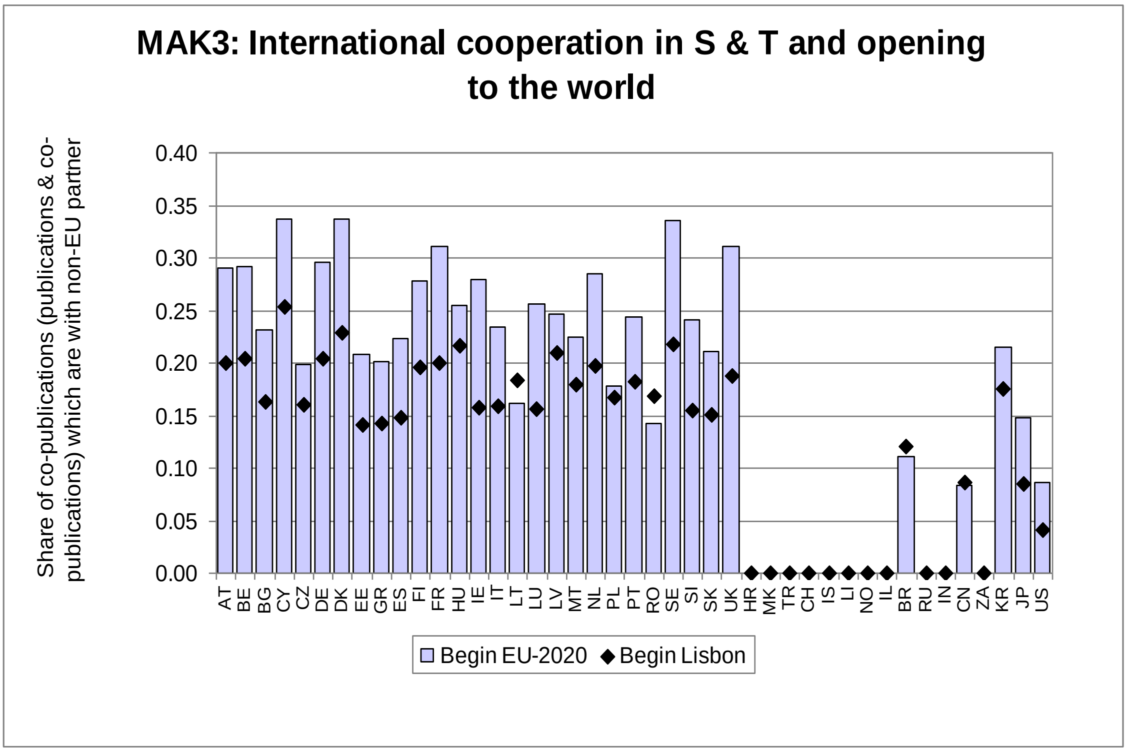
INP3: Activity level in knowledge producing activities
Total intramural R&D expenditure divided by GDP (PPP)
GERD/GDP
6.0
5.0
4.0
3.0
2.0
1.0
0.0
AT BE BG CY CZ DE DK EE GR ES FI FR HU IE IT LT LU LV MT NL PL PT RO SE SI SK UK HR MK TR CH IS LI NO IL BR RU IN CN ZA KR JP US
Begin EU-2020
Begin Lisbon

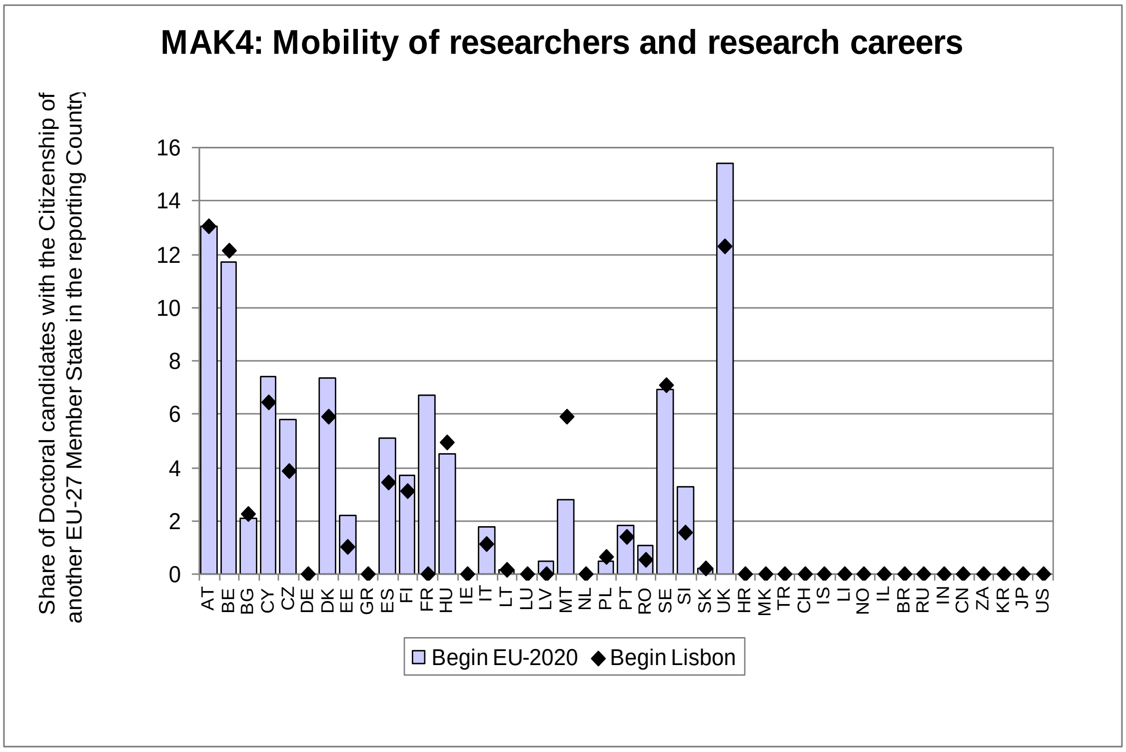


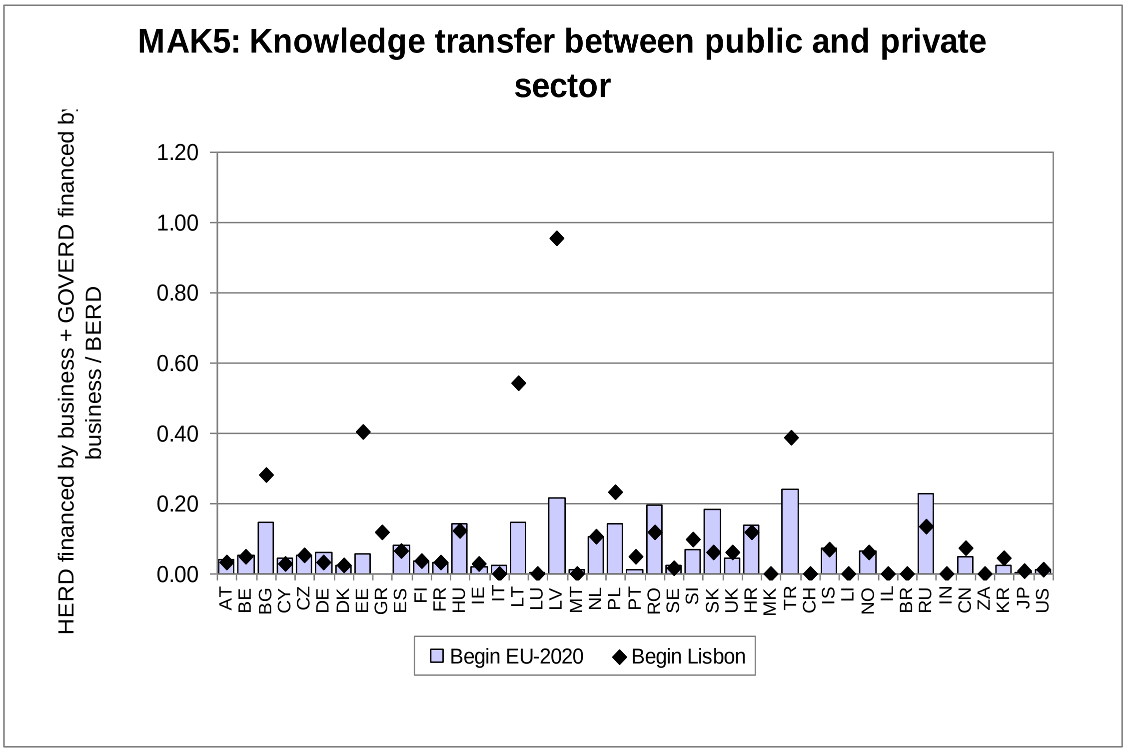
INP4: Strength of business research base
Business expenditure in RD (BERD) / GDP
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
AT BE BG CY CZ DE DK EE GR ES FI FR HU IE IT LT LU LV MT NL PL PT RO SE SI SK UK HR MK TR CH IS LI NO IL BR RU IN CN ZA KR JP US
Begin EU-2020
Begin Lisbon

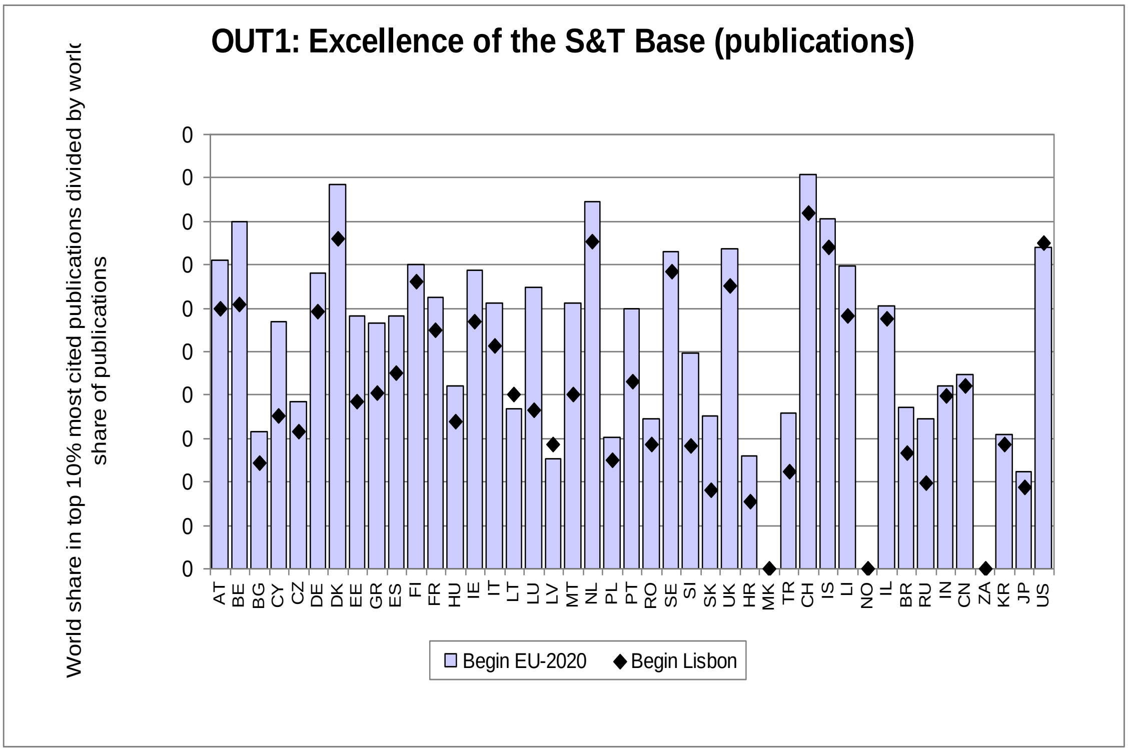

MAK1: ERA research actors cooperation
Share of co-publications (publications & co-publications) which are with EU partners, among which with the10 Membe States with the lowest R&D intensity
0.6
0.5
0.4
0.3
0.2
0.1
0.0
AT BE BG CY CZ DE DK EE GR ES FI FR HU IE IT LT LU LV MT NL PL PT RO SE SI SK UK HR MK TR CH IS LI NO IL BR RU IN CN ZA KR JP US
Begin EU-2020
Begin Lisbon

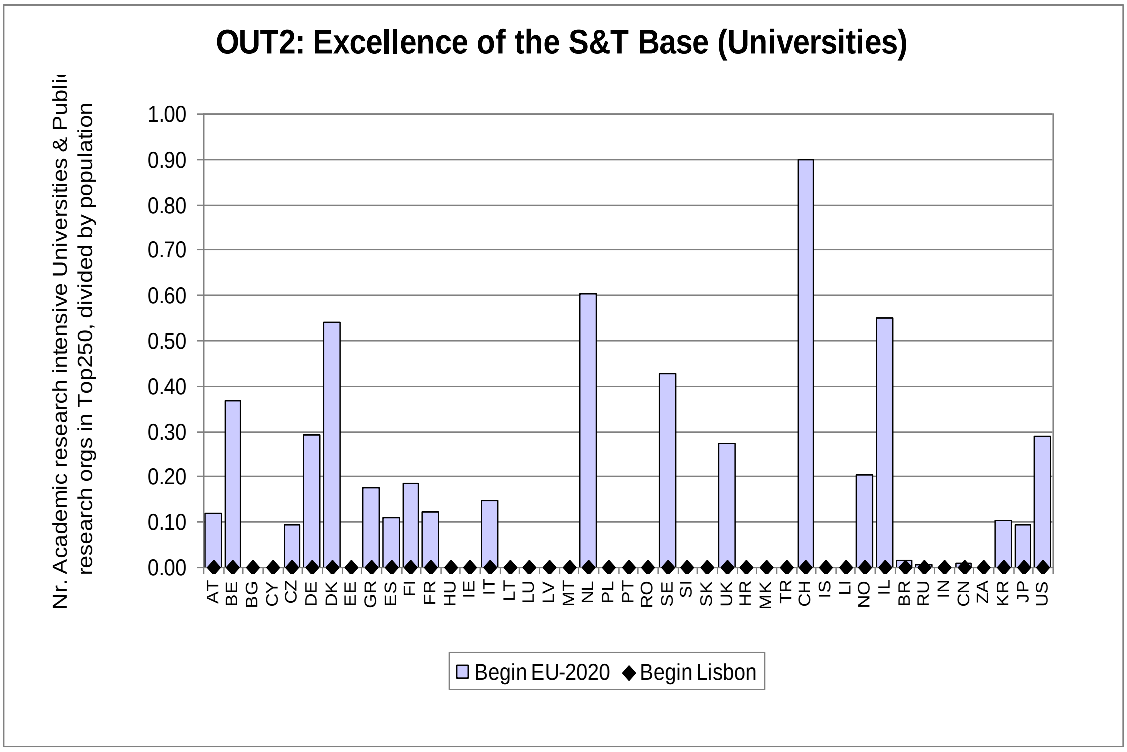

MAK2: – ERA research actors cohesion
Nr. CoPublication with 10 Lowest RD EU Partners / Tota nbr. of publications, incl co-publication
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
AT BE BG CY CZ DE DK EE GR ES FI FR HU IE IT LT LU LV MT NL PL PT RO SE SI SK UK HR MK TR CH IS LI NO IL BR RU IN CN ZA KR JP US
Begin EU-2020
Begin Lisbon

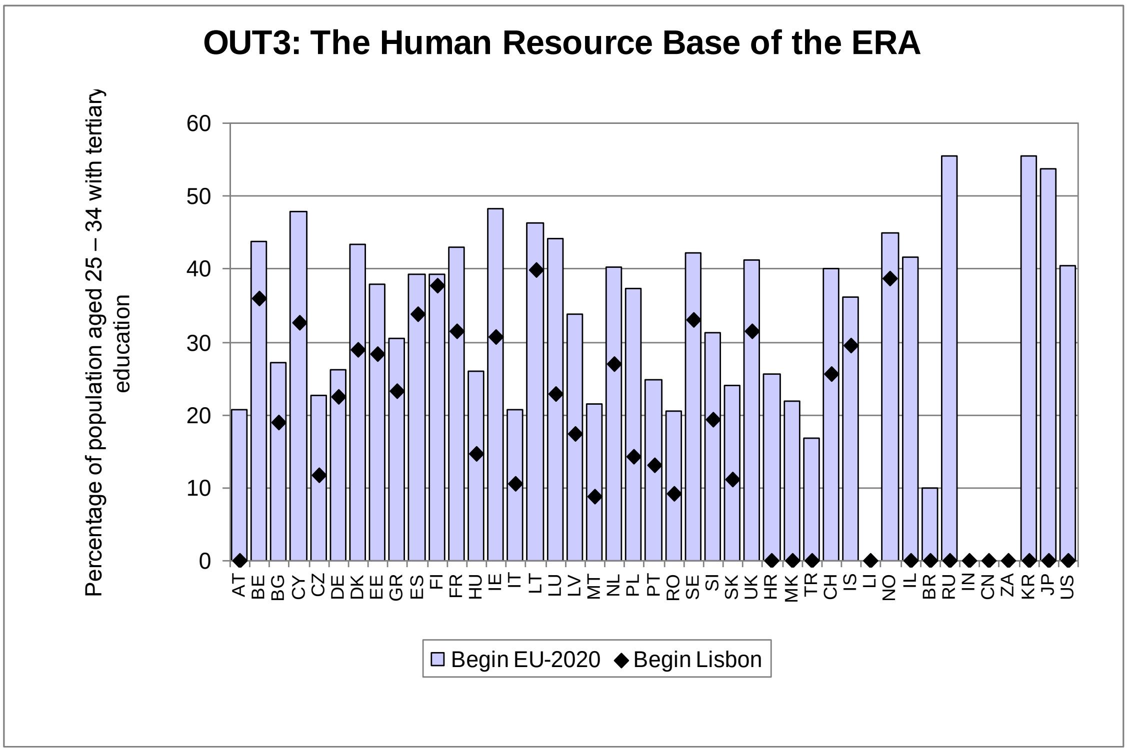

MAK3: International cooperation in S & T and opening to the world
Share of co-publications (publications & co-publications) which are with non-EU partner
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
AT BE BG CY CZ DE DK EE GR ES FI FR HU IE IT LT LU LV MT NL PL PT RO SE SI SK UK HR MK TR CH IS LI NO IL BR RU IN CN ZA KR JP US
Begin EU-2020
Begin Lisbon

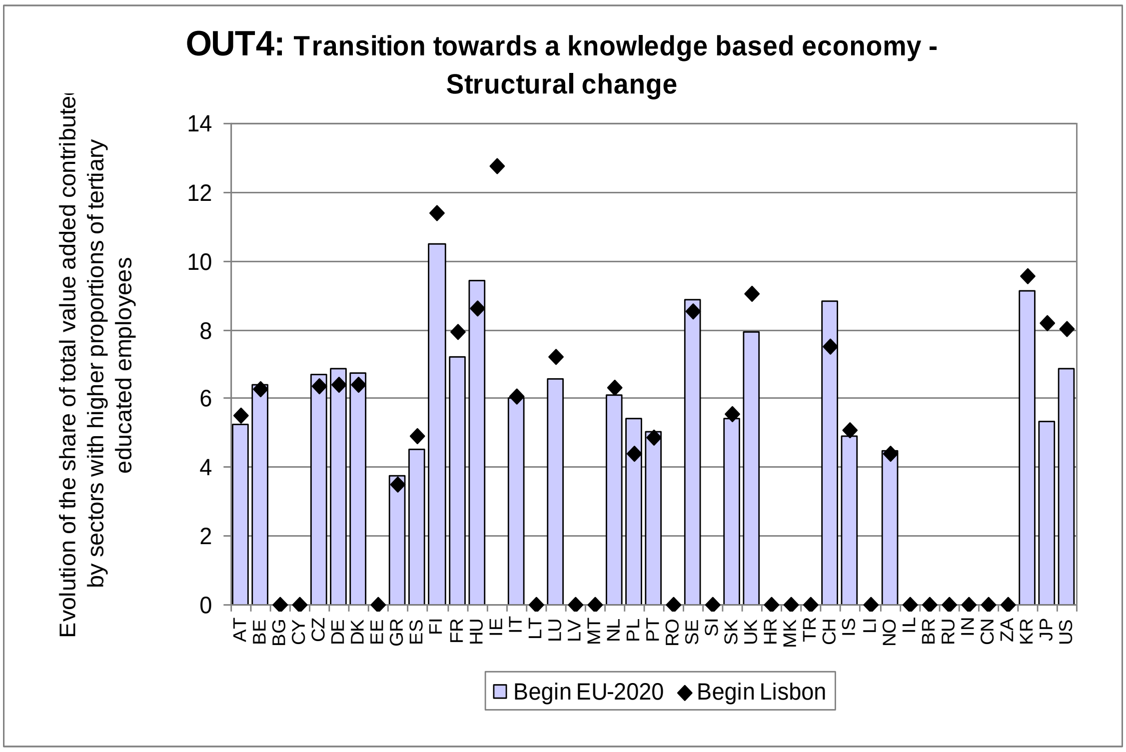

MAK4: Mobility of researchers and research careers
Share of Doctoral candidates with the Citizenship of another EU-27 Member State in the reporting Country
16
14
12
10
8
6
4
2
0
AT BE BG CY CZ DE DK EE GR ES FI FR HU IE IT LT LU LV MT NL PL PT RO SE SI SK UK HR MK TR CH IS LI NO IL BR RU IN CN ZA KR JP US
Begin EU-2020
Begin Lisbon

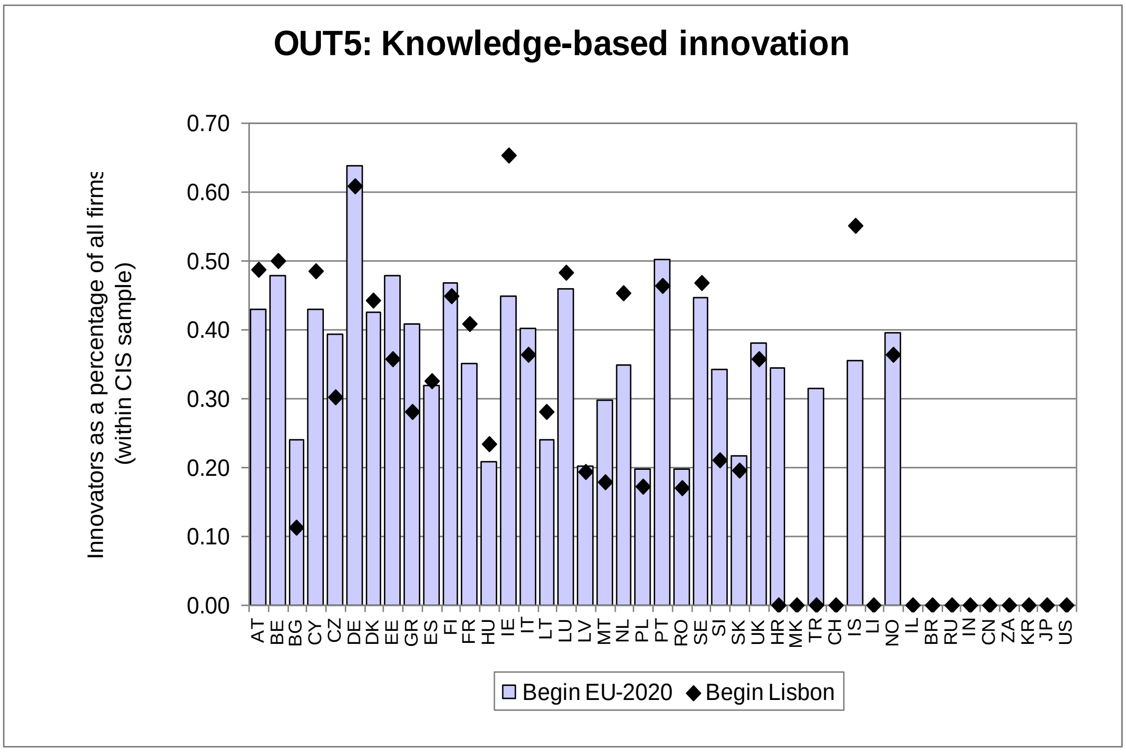

MAK5: Knowledge transfer between public and private sector
HERD financed by business + GOVERD financed by business / BERD
1.20
1.00
0.80
0.60
0.40
0.20
0.00
AT BE BG CY CZ DE DK EE GR ES FI FR HU IE IT LT LU LV MT NL PL PT RO SE SI SK UK HR MK TR CH IS LI NO IL BR RU IN CN ZA KR JP US
Begin EU-2020
Begin Lisbon

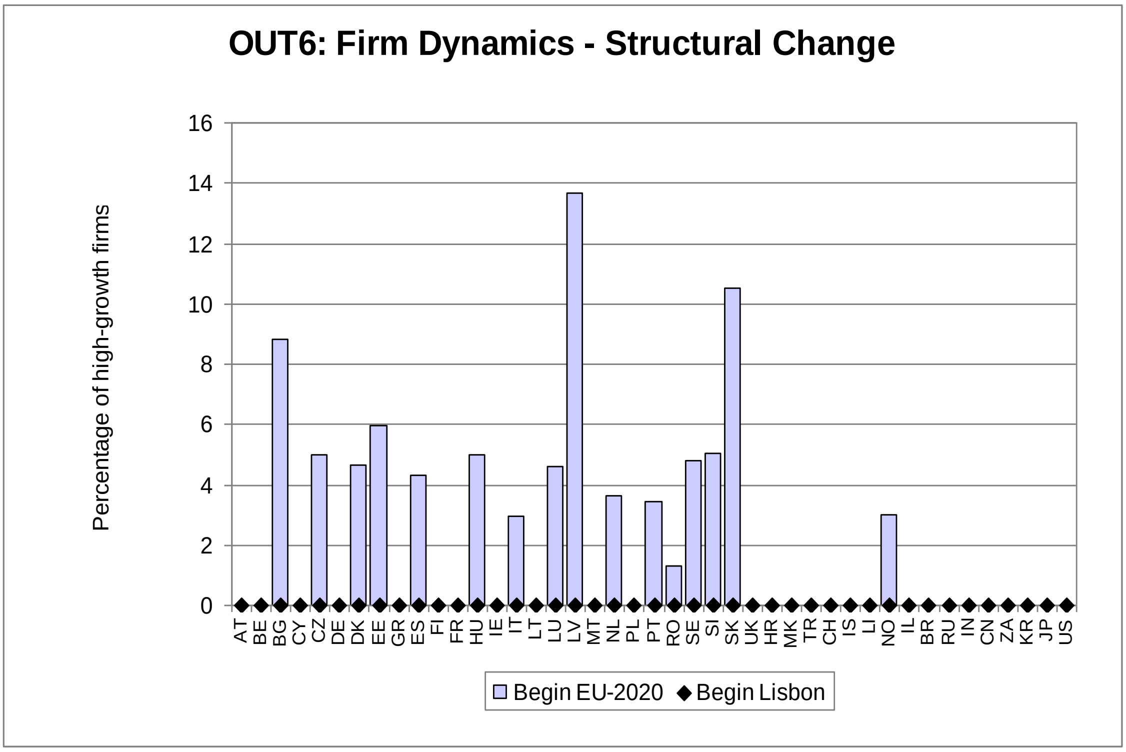

OUT1: Excellence of the S&T Base (publications)
World share in top 10% most cited publications divided by world share of publications
0
AT BE BG CY CZ DE DK EE GR ES FI FR HU IE IT LT LU LV MT NL PL PT RO SE SI SK UK HR MK TR CH IS LI NO IL BR RU IN CN ZA KR JP US
Begin EU-2020
Begin Lisbon


OUT2: Excellence of the S&T Base (Universities)
Nr. Academic research intensive Universities & Public research orgs in Top250, divided by population
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
AT BE BG CY CZ DE DK EE GR ES FI FR HU IE IT LT LU LV MT NL PL PT RO SE SI SK UK HR MK TR CH IS LI NO IL BR RU IN CN ZA KR JP US
Begin EU-2020
Begin Lisbon

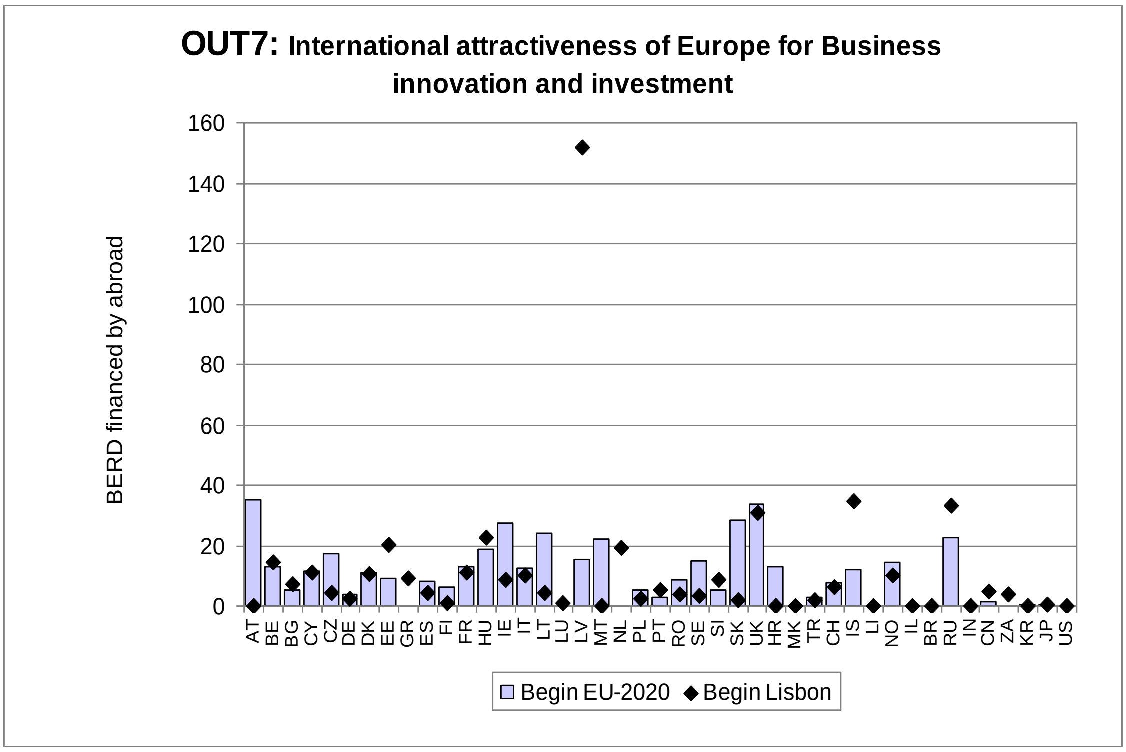

OUT3: The Human Resource Base of the ERA
Percentage of population aged 25 – 34 with tertiary education
60
50
40
30
20
10
0
AT BE BG CY CZ DE DK EE GR ES FI FR HU IE IT LT LU LV MT NL PL PT RO SE SI SK UK HR MK TR CH IS LI NO IL BR RU IN CN ZA KR JP US
Begin EU-2020
Begin Lisbon


OUT4: Transition towards a knowledge based economy - Structural change
Evolution of the share of total value added contributed by sectors with higher proportions of tertiary educated employees
14
12
10
8
6
4
2
0
AT BE BG CY CZ DE DK EE GR ES FI FR HU IE IT LT LU LV MT NL PL PT RO SE SI SK UK HR MK TR CH IS LI NO IL BR RU IN CN ZA KR JP US
Begin EU-2020
Begin Lisbon

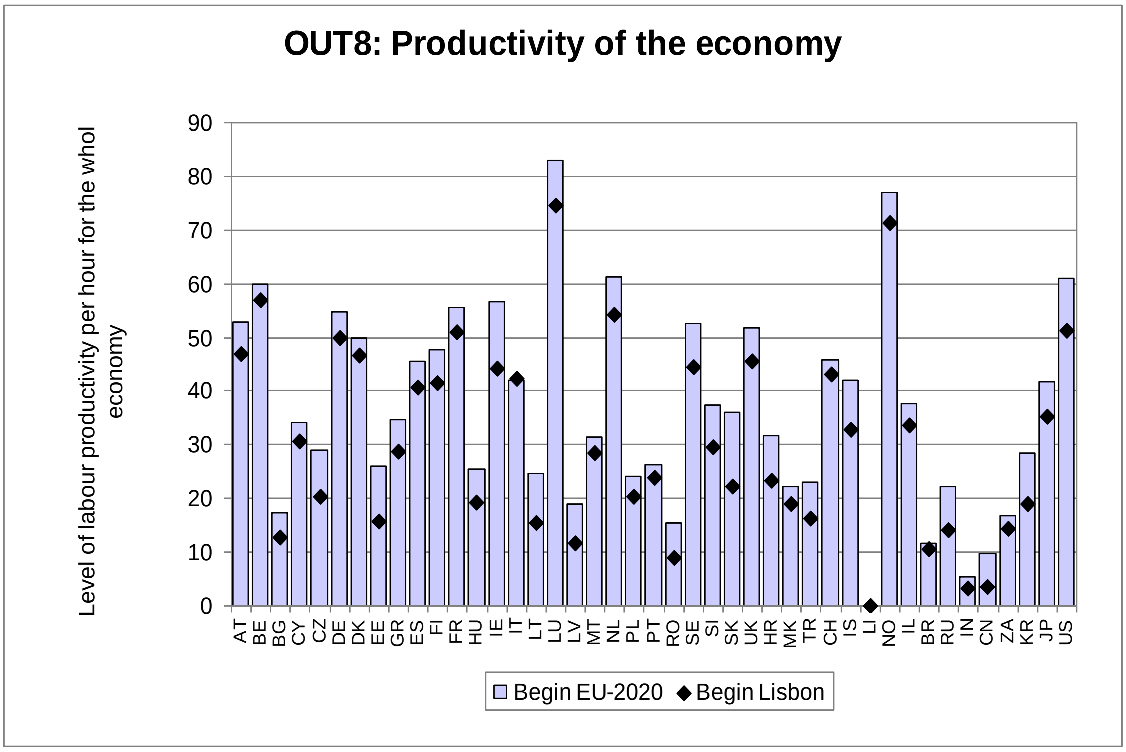

OUT5: Knowledge-based innovation
Innovators as a percentage of all firms (within CIS sample)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
AT BE BG CY CZ DE DK EE GR ES FI FR HU IE IT LT LU LV MT NL PL PT RO SE SI SK UK HR MK TR CH IS LI NO IL BR RU IN CN ZA KR JP US
Begin EU-2020
Begin Lisbon

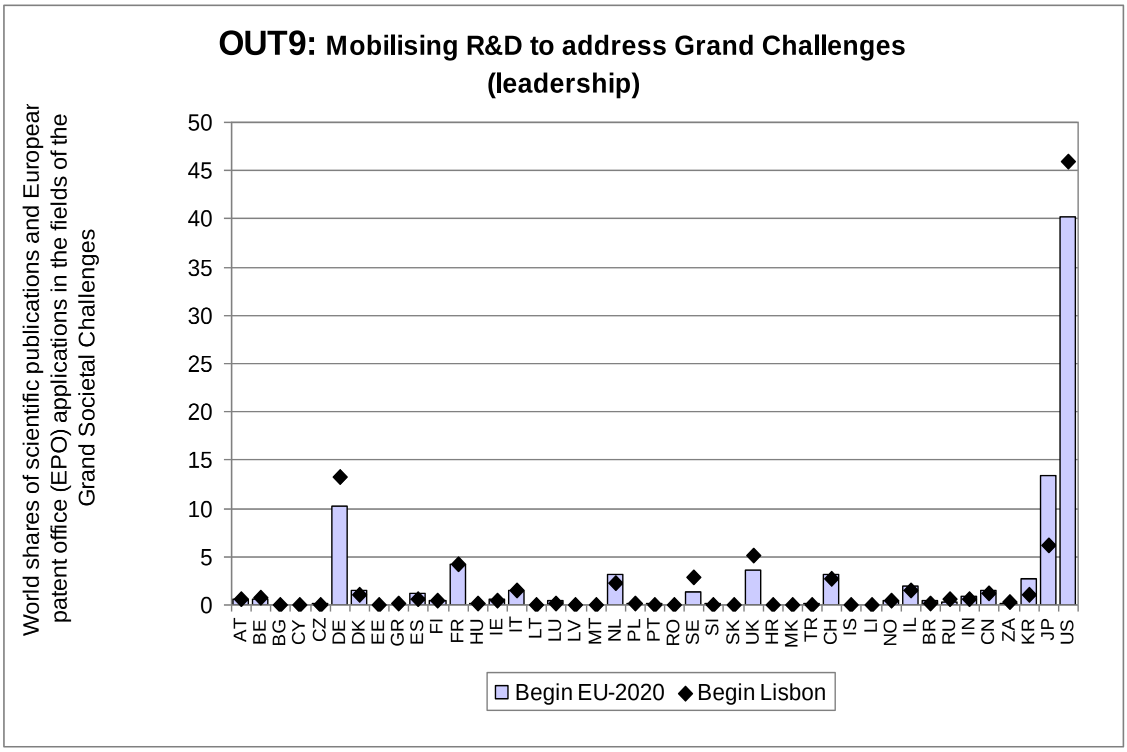


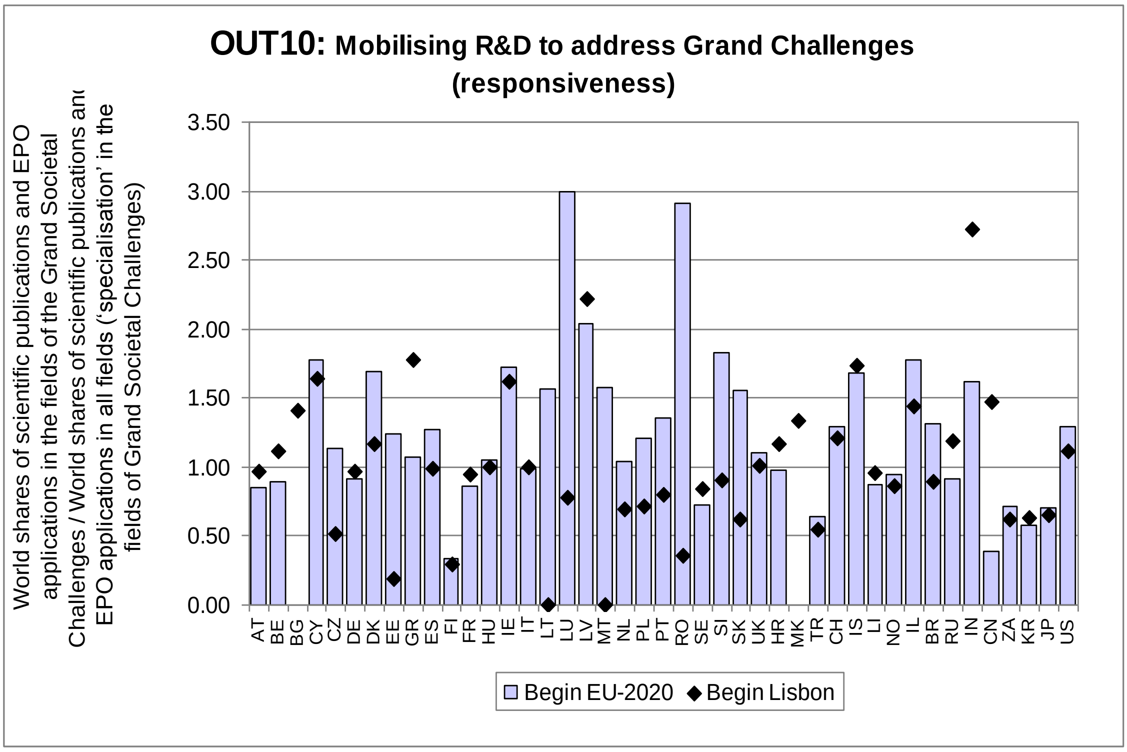
OUT6: Firm Dynamics - Structural Change
Percentage of high-growth firms
16
14
12
10
8
6
4
2
0
AT BE BG CY CZ DE DK EE GR ES FI FR HU IE IT LT LU LV MT NL PL PT RO SE SI SK UK HR MK TR CH IS LI NO IL BR RU IN CN ZA KR JP US
Begin EU-2020
Begin Lisbon



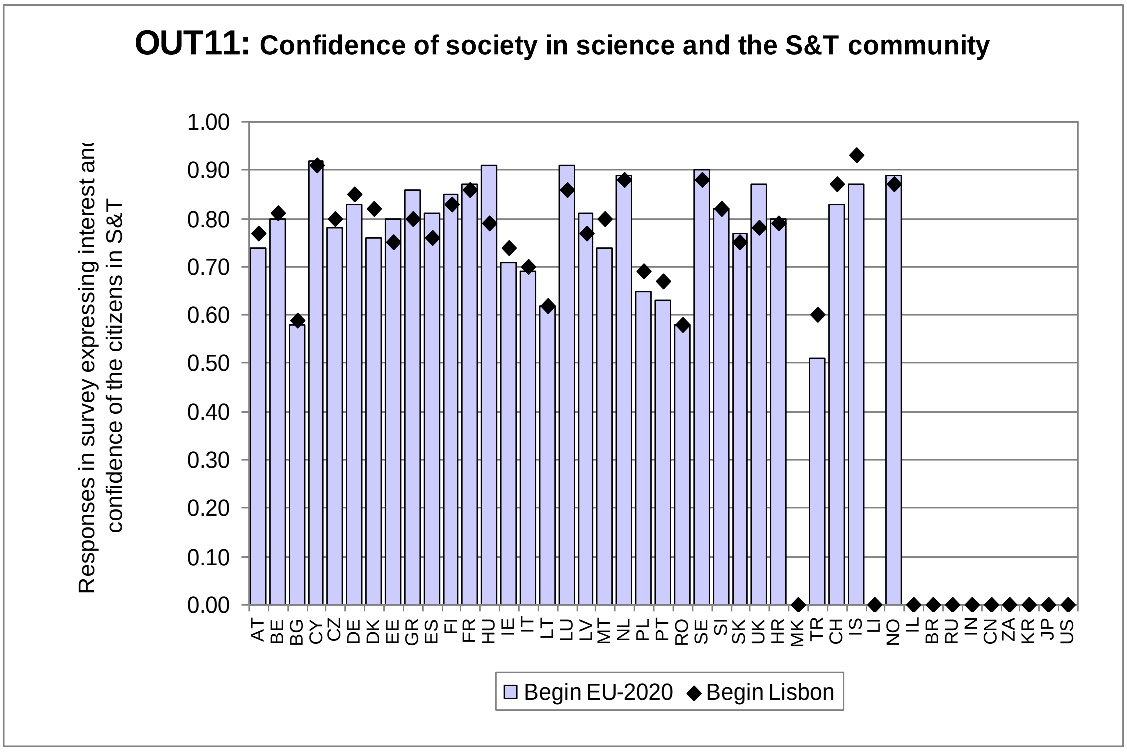
OUT7: International attractiveness of Europe for Business innovation and investment
BERD financed by abroad
160
140
120
100
80
60
40
20
0
AT BE BG CY CZ DE DK EE GR ES FI FR HU IE IT LT LU LV MT NL PL PT RO SE SI SK UK HR MK TR CH IS LI NO IL BR RU IN CN ZA KR JP US
Begin EU-2020
Begin Lisbon


OUT8: Productivity of the economy
Level of labour productivity per hour for the whol economy
90
80
70
60
50
40
30
20
10
0
AT BE BG CY CZ DE DK EE GR ES FI FR HU IE IT LT LU LV MT NL PL PT RO SE SI SK UK HR MK TR CH IS LI NO IL BR RU IN CN ZA KR JP US
Begin EU-2020
Begin Lisbon


OUT9: Mobilising R&D to address Grand Challenges (leadership)
World shares of scientific publications and Europear patent office (EPO) applications in the fields of the Grand Societal Challenges
50
45
40
35
30
25
20
15
10
5
0
AT BE BG CY CZ DE DK EE GR ES FI FR HU IE IT LT LU LV MT NL PL PT RO SE SI SK UK HR MK TR CH IS LI NO IL BR RU IN CN ZA KR JP US
Begin EU-2020
Begin Lisbon



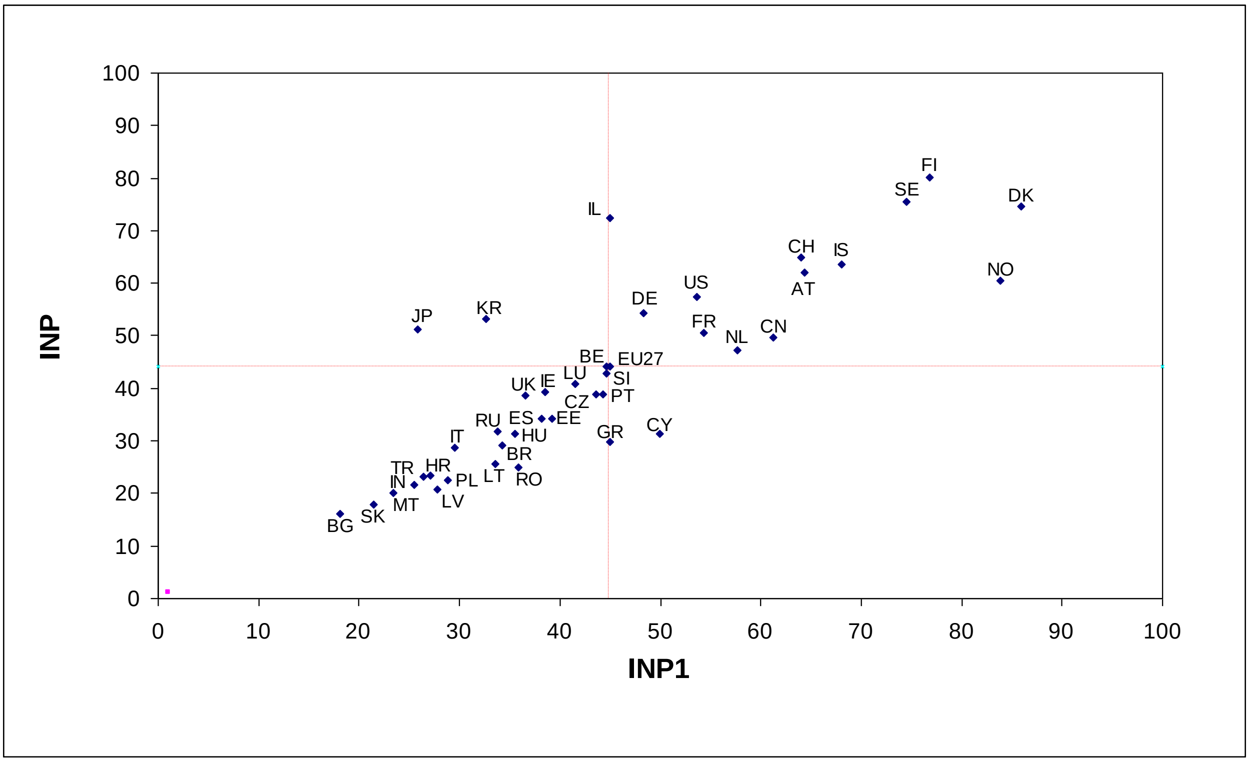
OUT10: Mobilising R&D to address Grand Challenges (responsiveness)
World shares of scientific publications and EPO applications in the fields of the Grand Societal Challenges / World shares of scientific publications and EPO applications in all fields ('specialisation' in the fields of Grand Societal Challenges)
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
AT BE BG CY CZ DE DK EE GR ES FI FR HU IE IT LT LU LV MT NL PL PT RO SE SI SK UK HR MK TR CH IS LI NO IL BR RU IN CN ZA KR JP US
Begin EU-2020
Begin Lisbon

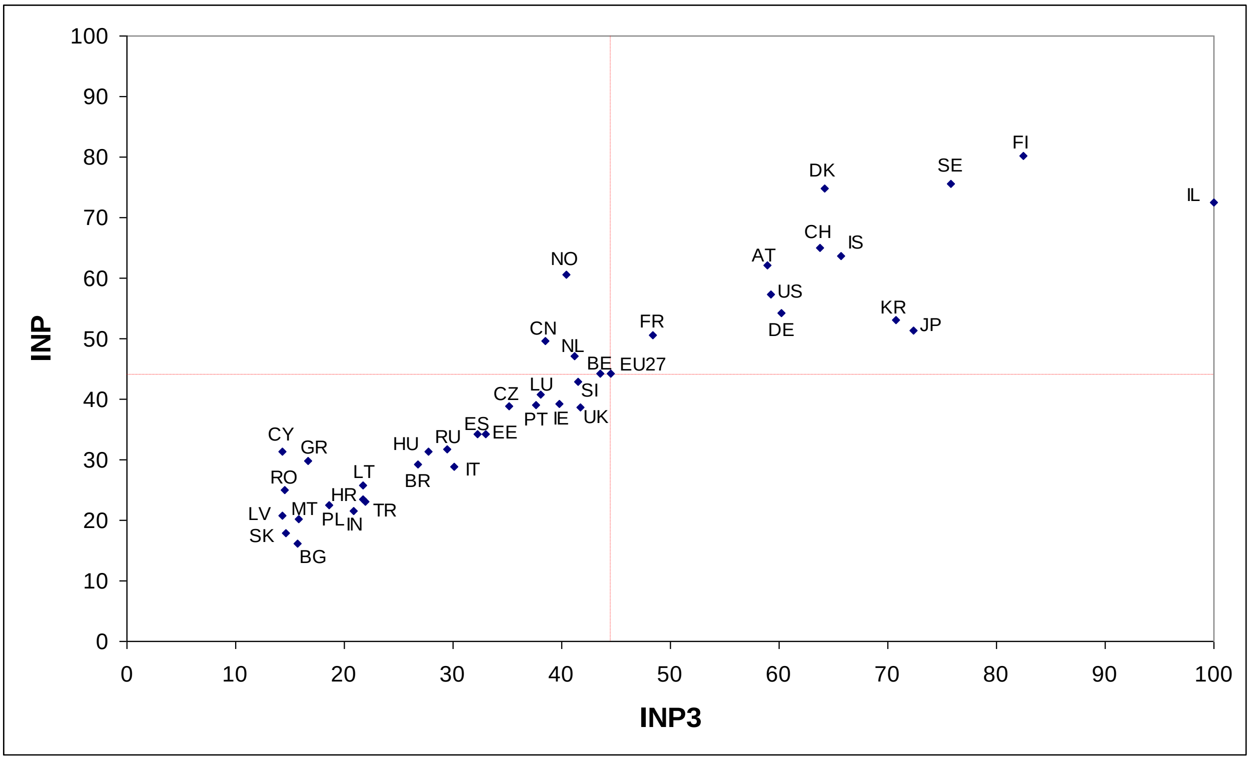


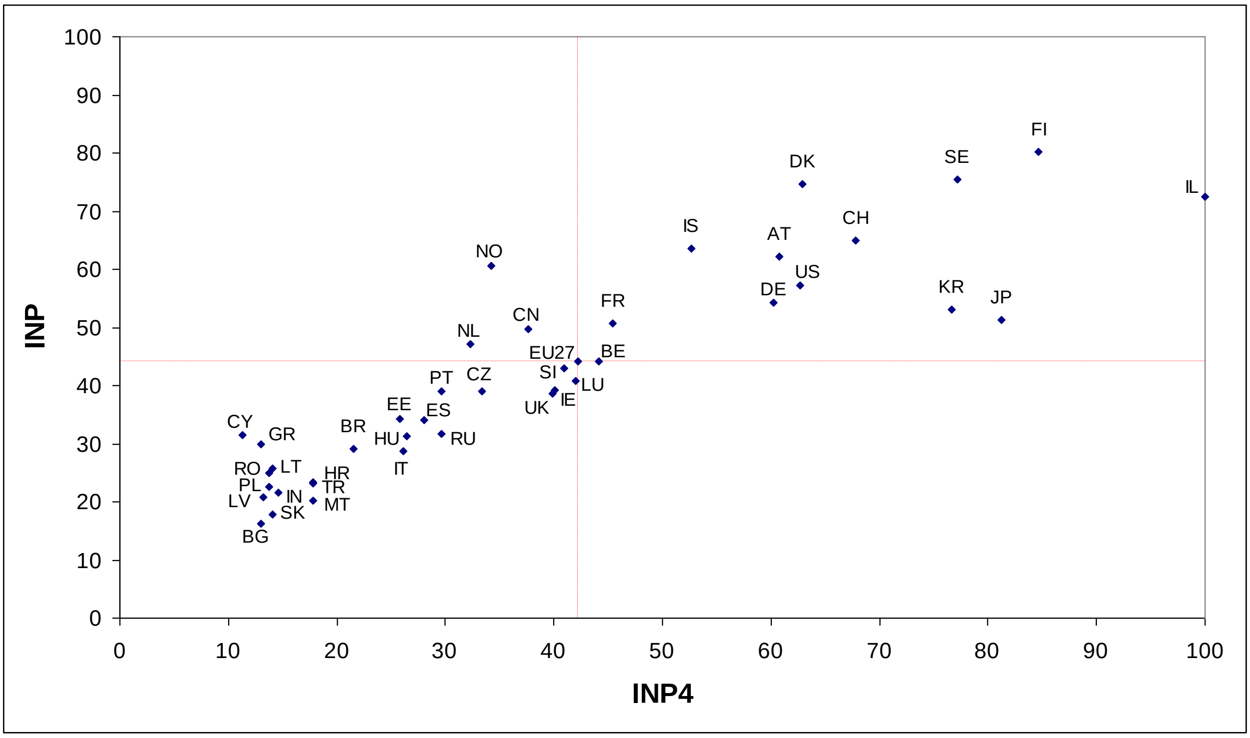
OUT11: Confidence of society in science and the S&T community
Responses in survey expressing interest and confidence of the citizens in S&T
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
AT BE BG CY CZ DE DK EE GR ES FI FR HU IE IT LT LU LV MT NL PL PT RO SE SI SK UK HR MK TR CH IS LI NO IL BR RU IN CN ZA KR JP US
Begin EU-2020
Begin Lisbon

ANNEX II

Scatterplots of indicators against their respective domains at *begin EU-2020* time point. Vertical axes report the composite scores by domain, horizontal axes give normalized scores for each indicator. Here we used minmax normalization, arithmetic average and hot-deck imputation.






INP
INP4
0
10
20
30
40
50
60
70
80
90
100
FI
DK
SE
IL
CH
IS
AT
US
NO
DE
KR
JP
FR
CN
NL
EU27
BE
SI
LU
PT
CZ
IE
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TR
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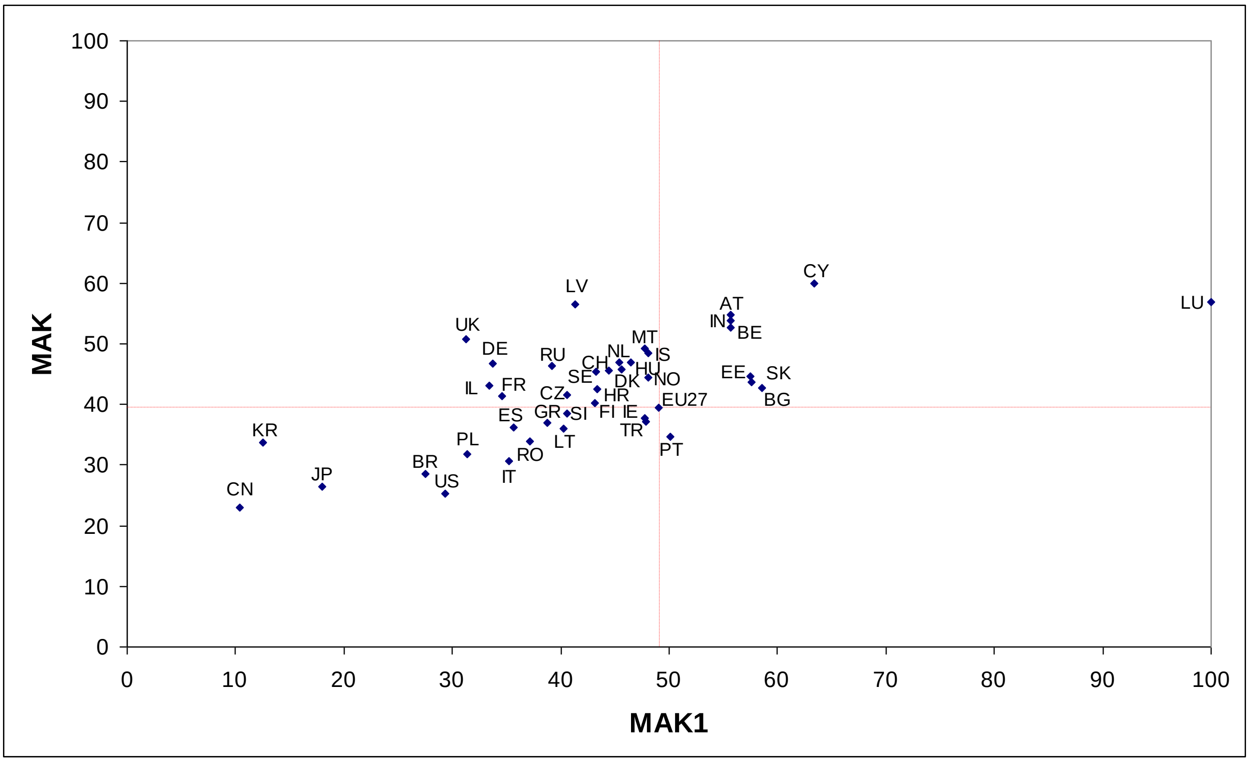
IN
MT
SK
BG


MAK
MAK1
0
10
20
30
40
50
60
70
80
90
100
CY
LV
AT
LU
IN
BE
UK
DE
MT
RU
NL
IS
CH
HU
SE
DK
NO
EE
SK
IL
FR
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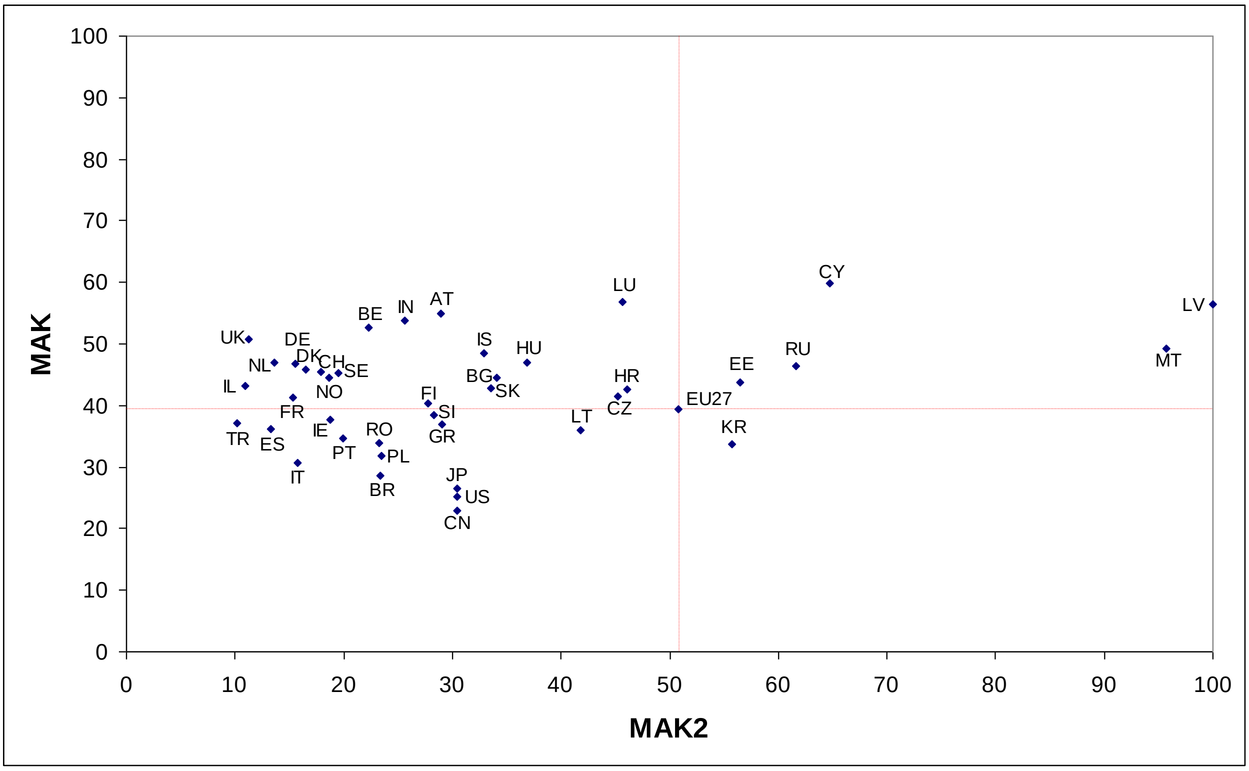
MAK
MAK2
UK
NL
IL
TR
DE
DK
CH
SE
NO
FR
ES
IE
IT
PT
BE
IN
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RO
PL
BR
FI
SI
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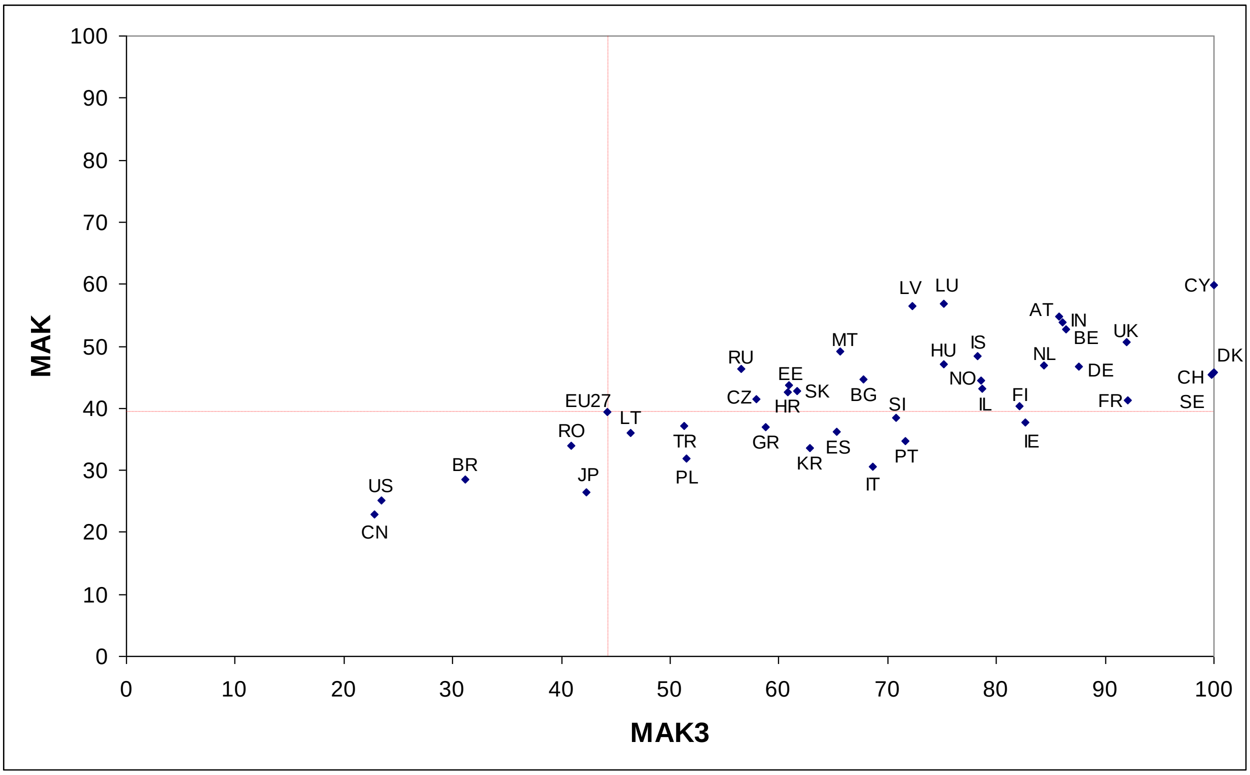
RU
CY
LV
MT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MAK3
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EU27
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PL
RU
CZ
EE
HR
SK
GR
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SI
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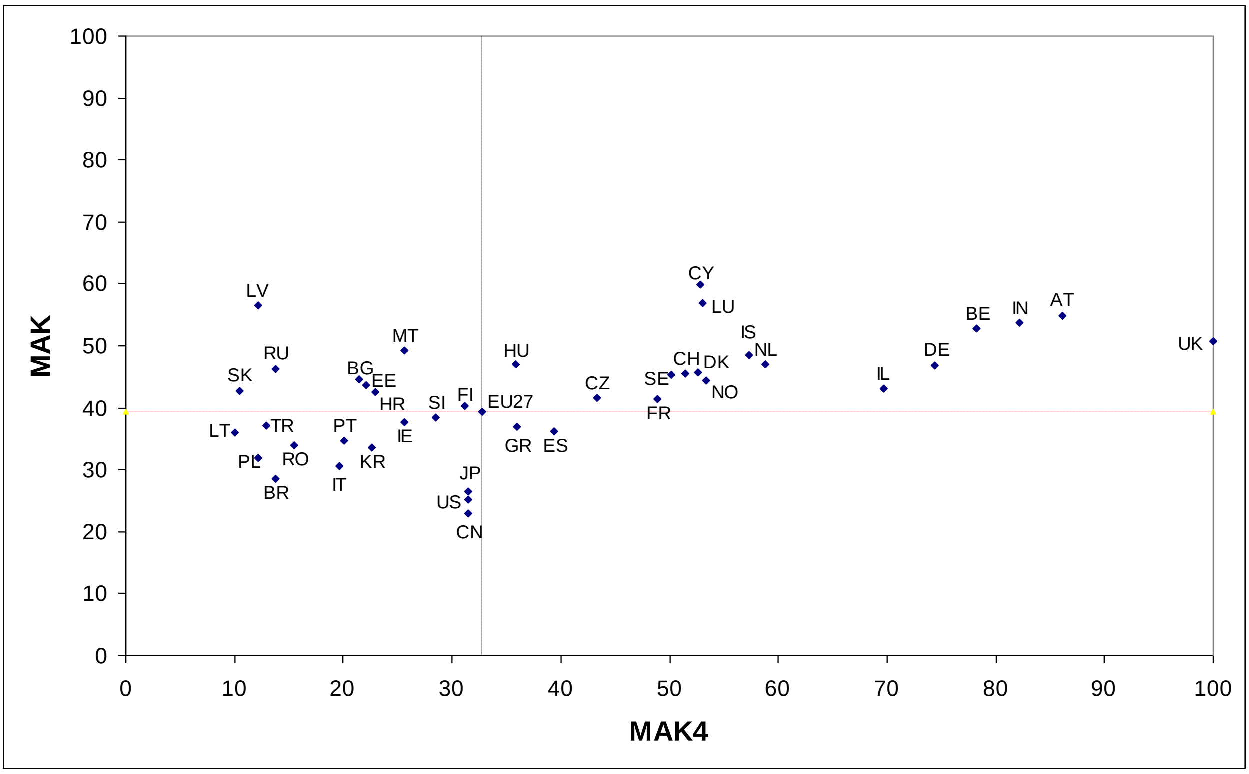
CH
SE


MAK
MAK4
100
90
80
70
60
50
40
30
20
10
0
0 10 20 30 40 50 60 70 80 90 100
LV
RU
SK
MT
BG
EE
HR
SI
FI
EU27
HU
CZ
SE
CH
DK
NO
CY
LU
IS
NL
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ES
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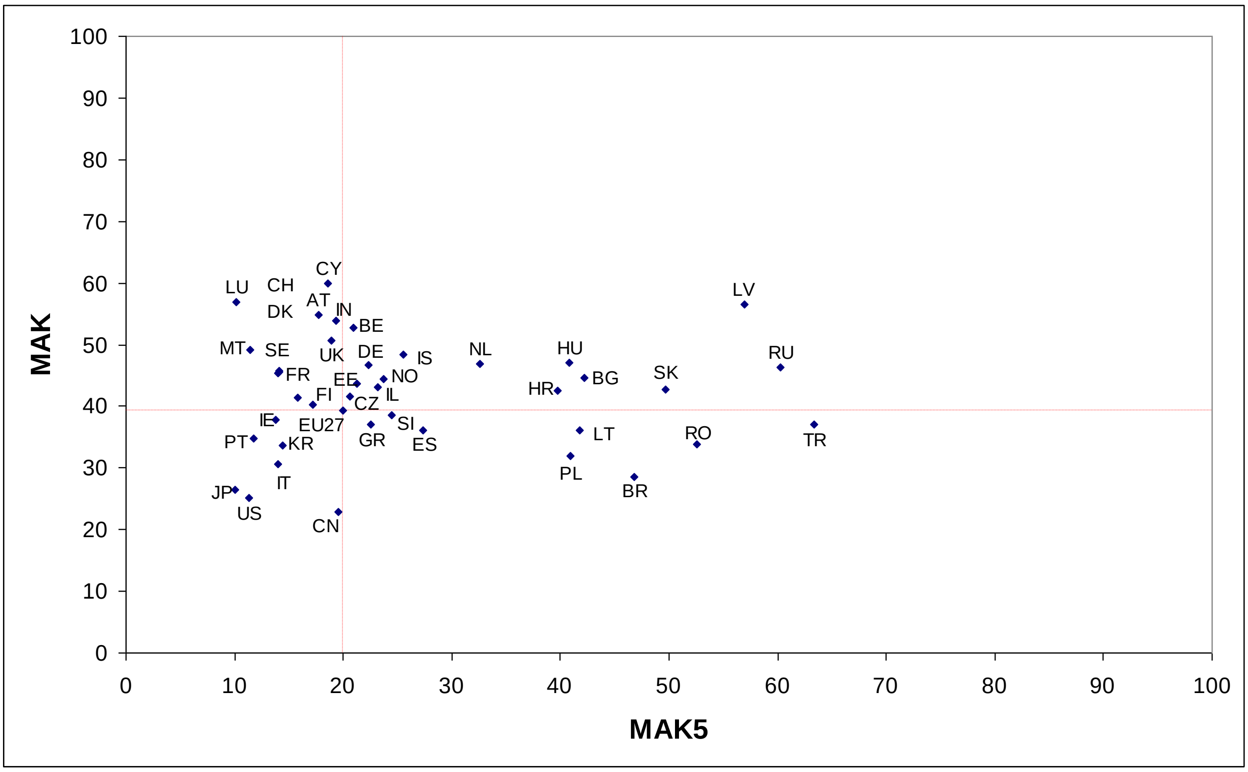
MAK
MAK5
100
90
80
70
60
50
40
30
20
10
0
0 10 20 30 40 50 60 70 80 90 100
LU
CH
DK
CY
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IN
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EU27
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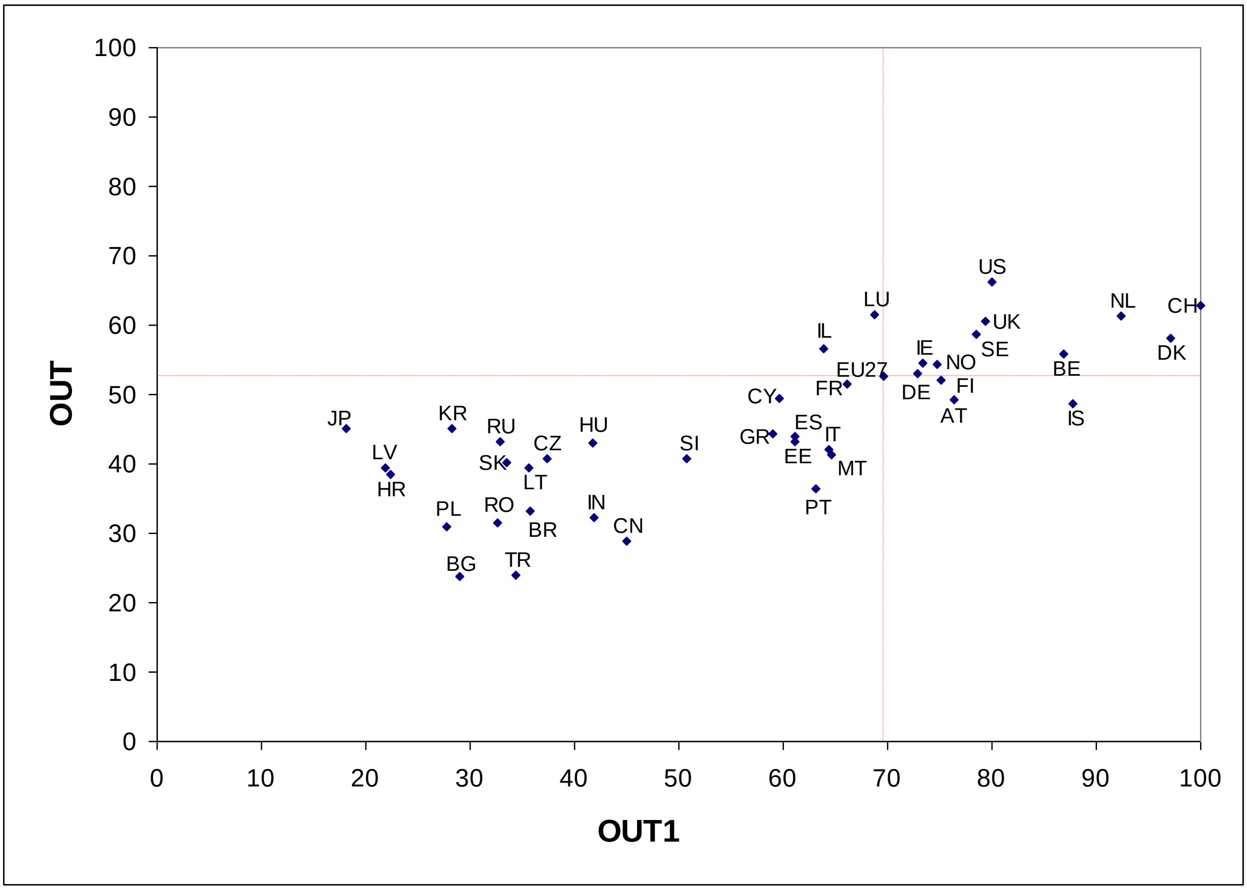
OUT
OUT1
JP
LV
HR
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PL
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RO
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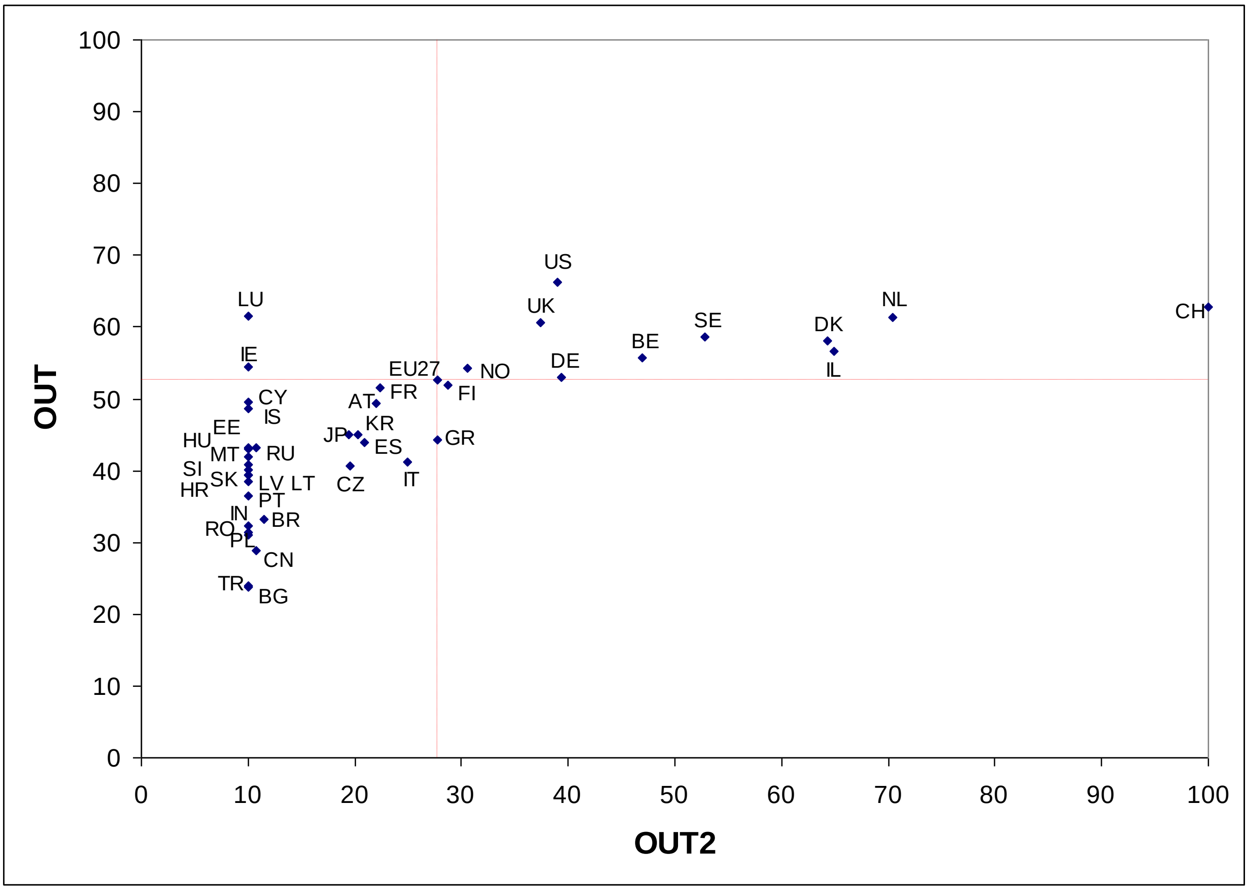
OUT
OUT2
LU
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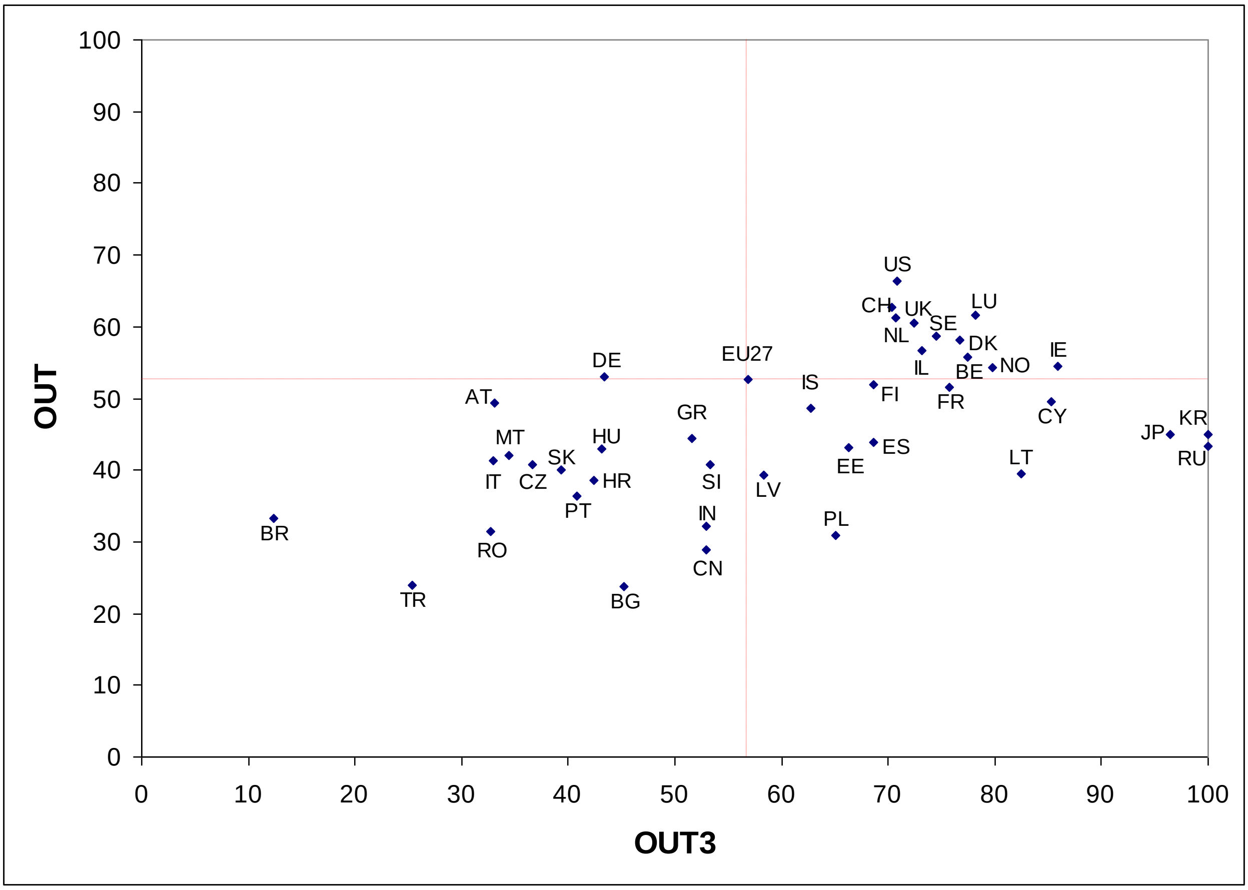
OUT
OUT3
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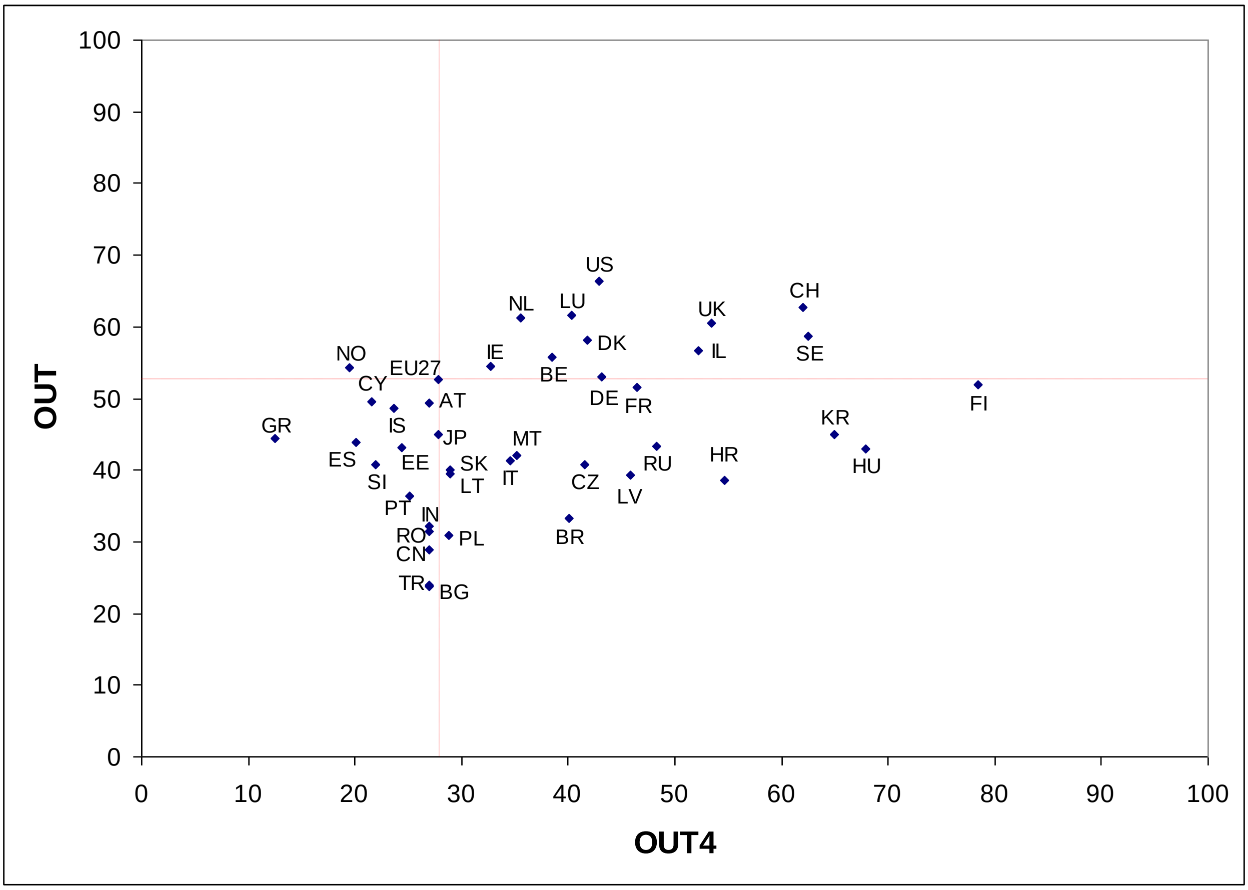
OUT
OUT4
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KR
JP
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CN
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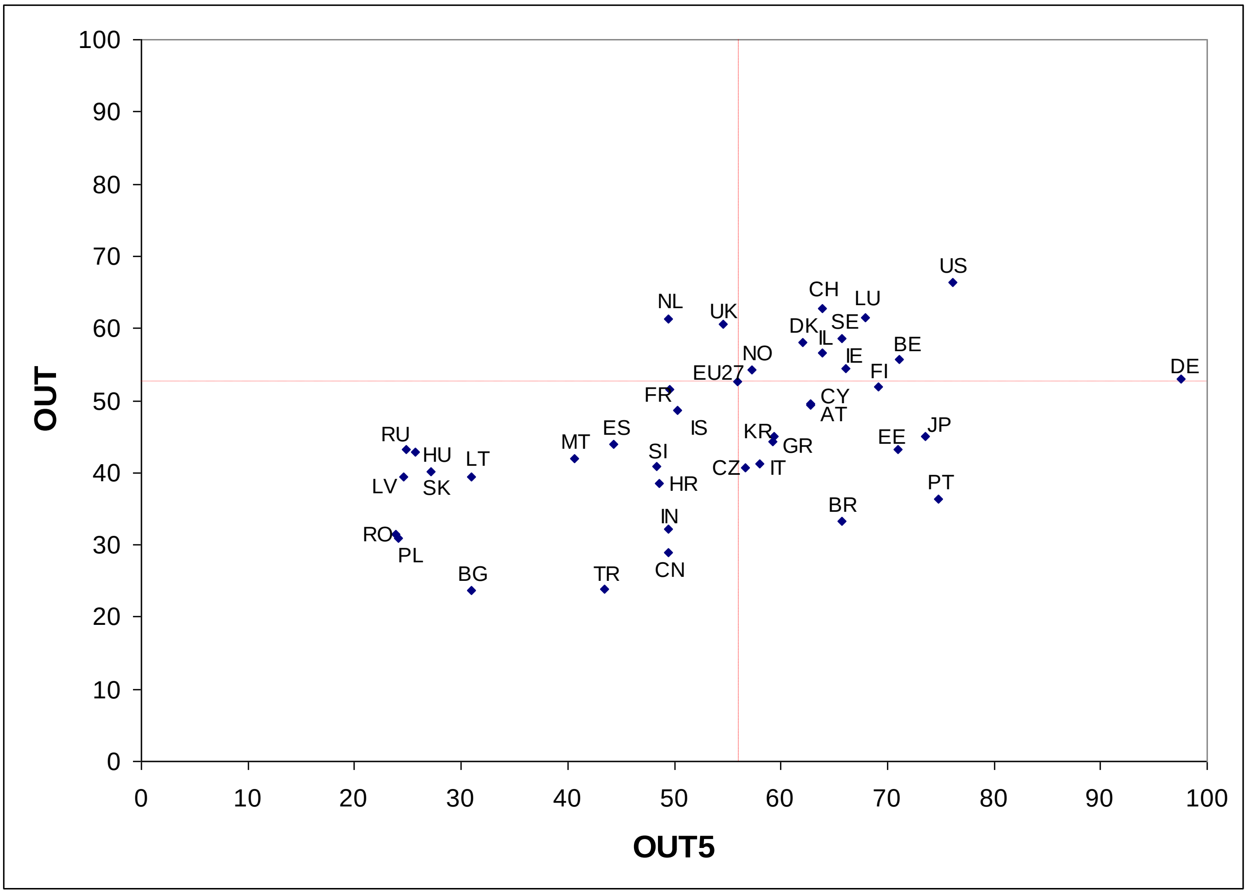
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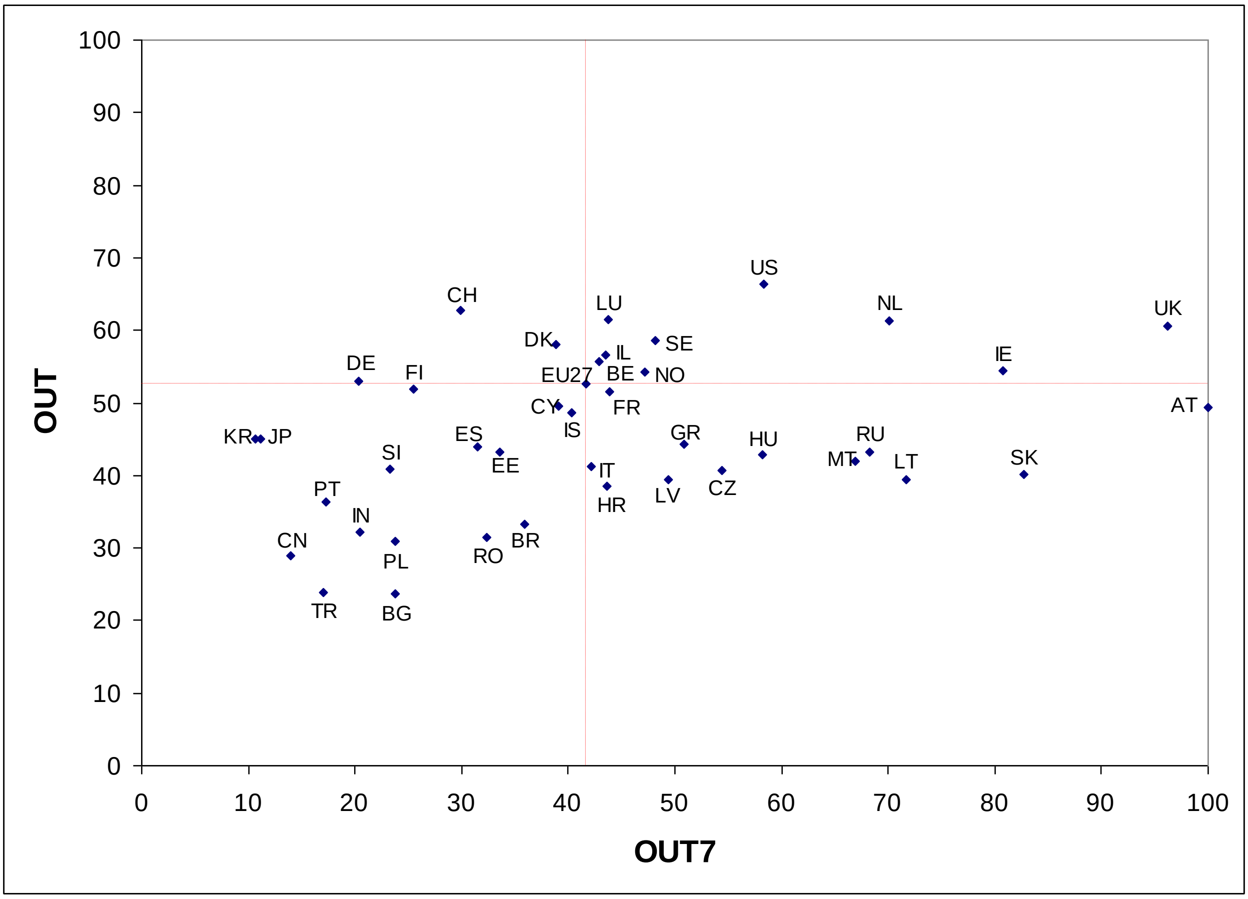
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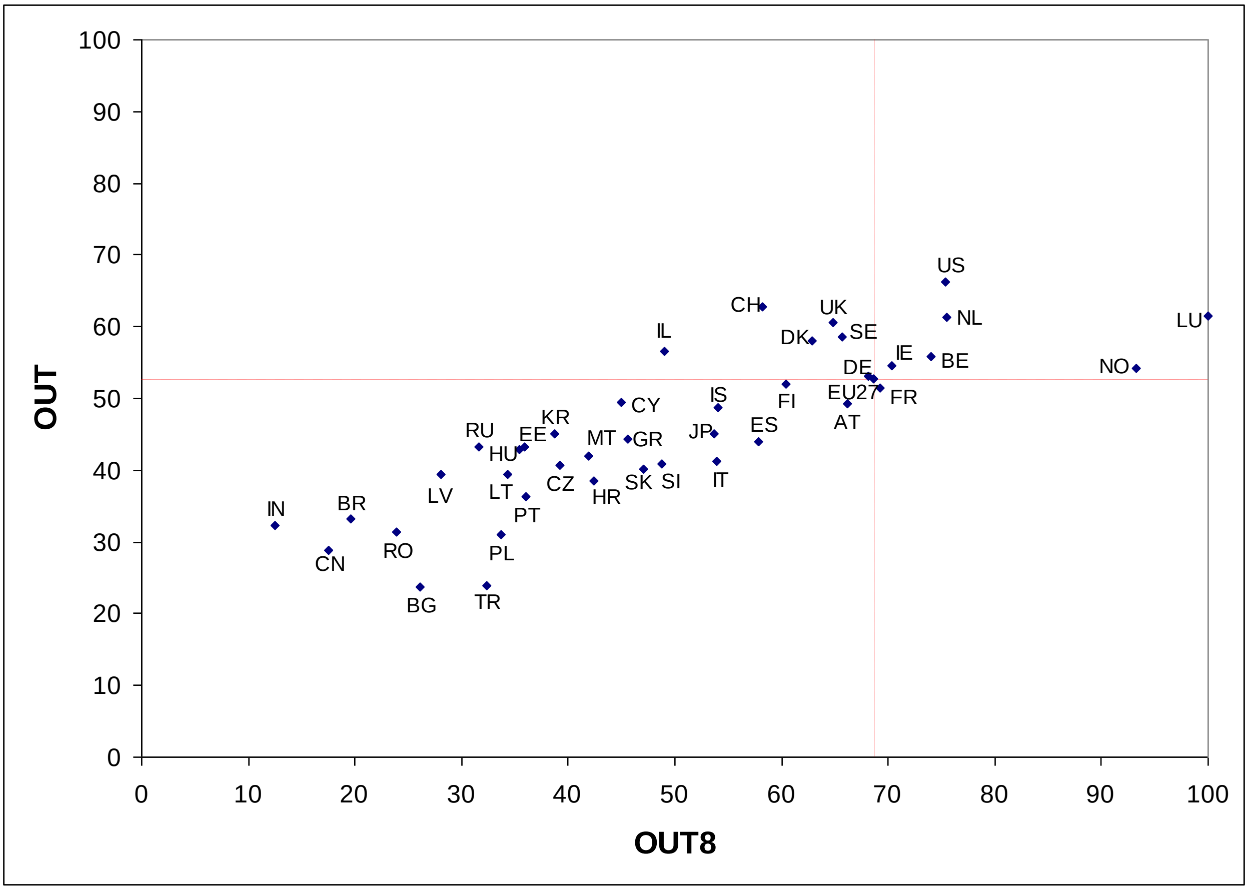
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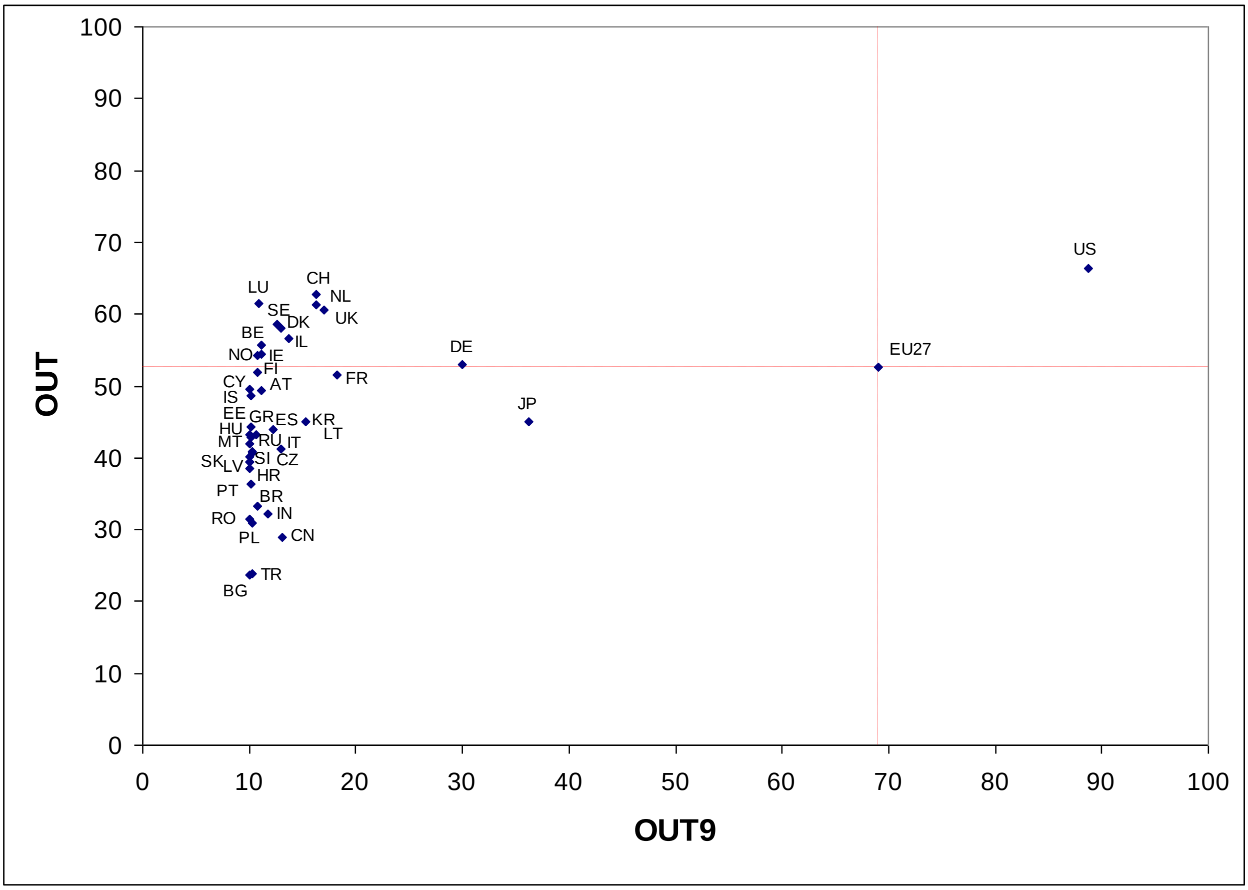
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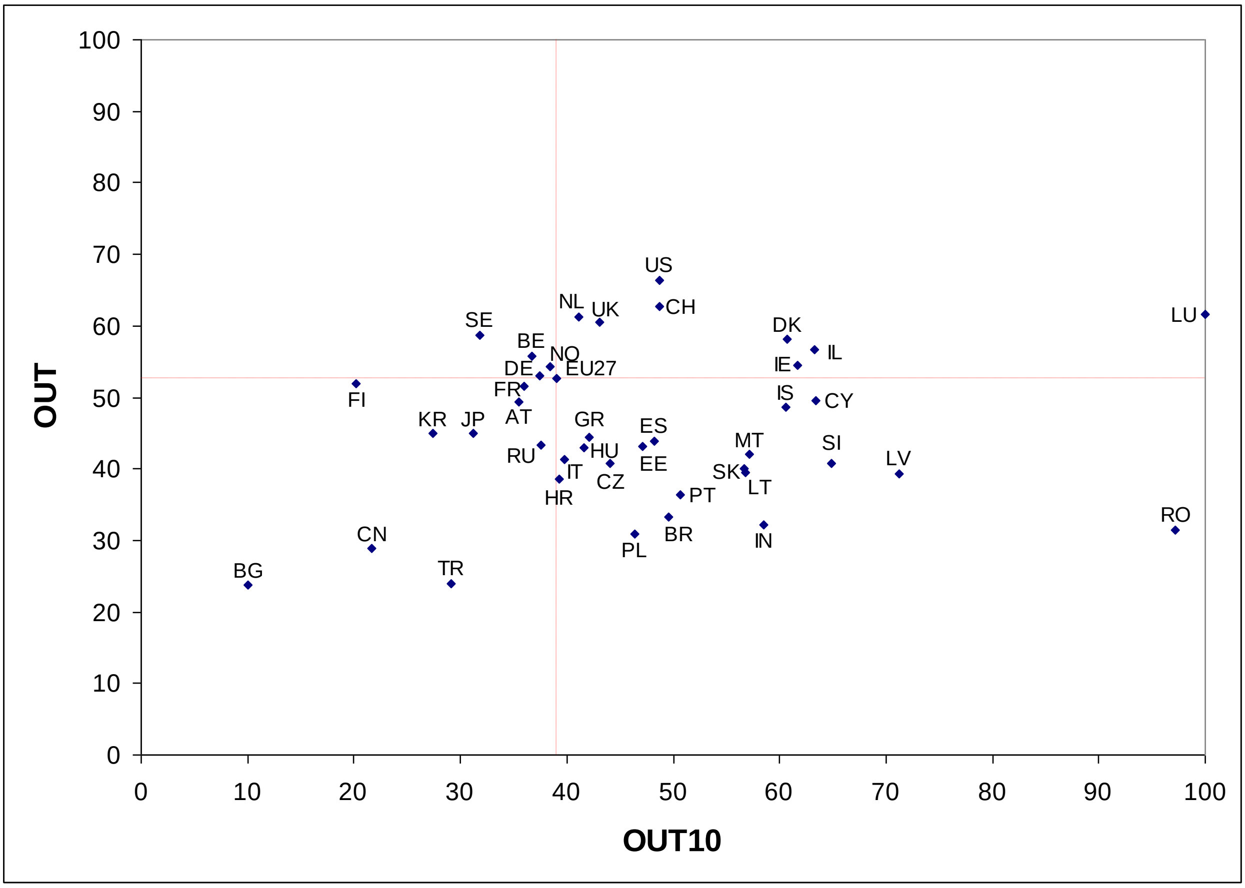

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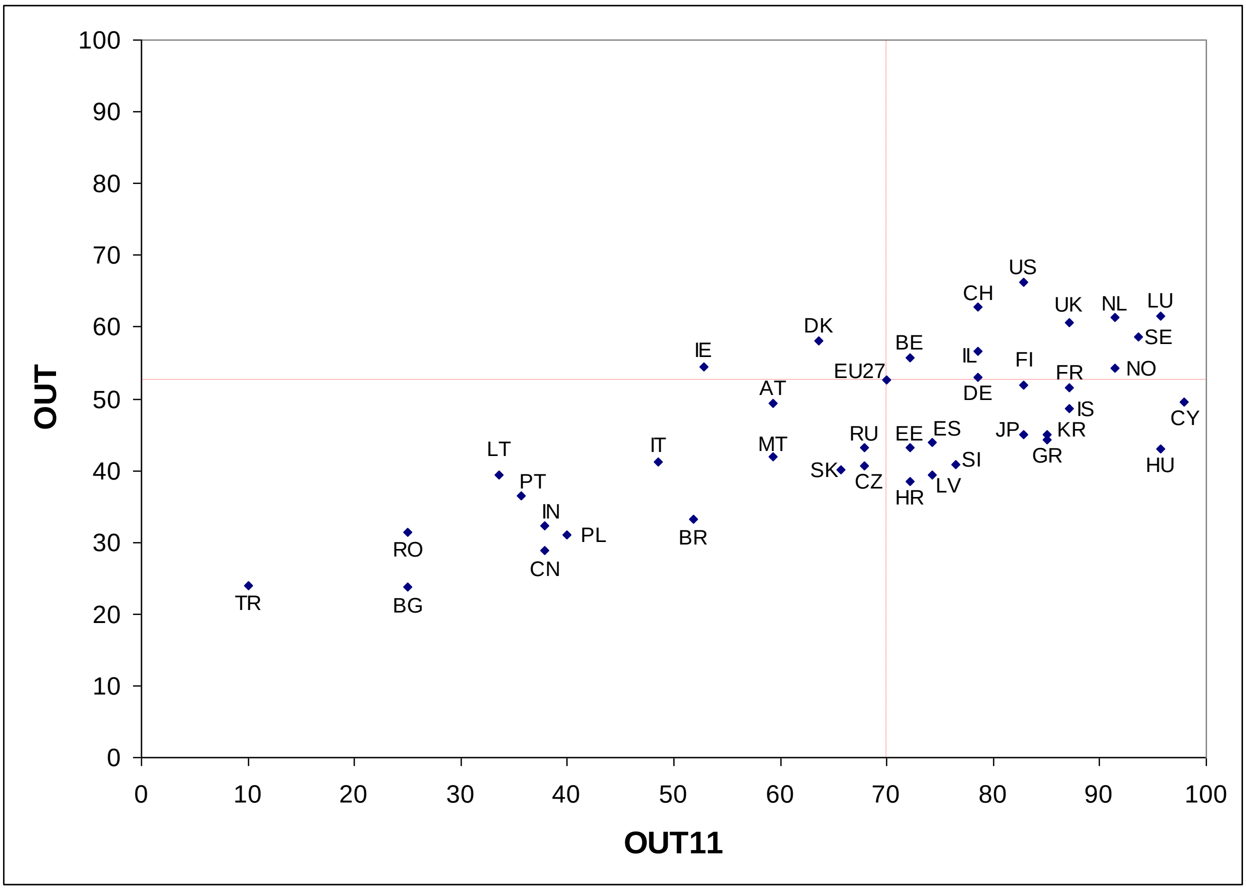

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Glossary

BERD:	Business Expenditure in Research and Development,
BRICS:	Brazil, Russia, India, China, South-Africa,
Candidate countries:	Croatia, Macedonia, Turkey,
CERN:	European Organization for Nuclear Research - Conseil Européen pour la Recherche Nucléaire,
CIS:	Community Innovation Survey (Eurostat)
CWTS:	Centre for Science and Technology Studies – Leiden Univ. - The Netherlands,
EFTA:	European Free Trade Association composed of Switzerland, Iceland, Liechtenstein, Norway,
EKS dollar:	Elteto-Koves-Szulc (EKS) method for data aggregation,
EMBL:	European Molecular Biology Laboratory,
EMBO:	European Molecular Biology Organisation,
EPO:	European Patent Office,
ERA countries:	Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Germany, Denmark, Estonia, Greece, Spain, Finland, France, Hungary, Ireland, Italy, Lithuania, Luxembourg, Latvia, Malta, Netherlands, Poland, Portugal, Romania, Sweden, Slovenia, Slovakia, United Kingdom, Croatia, Macedonia, Turkey, Switzerland, Iceland, Liechtenstein, Norway, Israel,
ERIC:	Education Resources Information Center,
ERSF:	international research institute for cutting-edge science with photons,
ESFRI:	European Strategy Forum on Research Infrastructures,
ESO:	European Southern Observatory - Organisation for Astronomical Research in the Southern Hemisphere,
Eurostat:	Statistical office of the European Union,
FYROM:	Former Yugoslav Republic Of Macedonia,
GBAORD:	Government Budget Appropriations Outlays for R & D,
GERD:	Gross expenditure on R&D,
GOVERD:	Govern Intramural Expenditures in R&D,
Grand Challenges:	Health, Energy, Environment (including Climate Change), Food, Agriculture, Fisheries,
ILL:	Institut Laue-Langevin,
IPC:	International Patent Classification,
HERD:	High Educational Research and Development,
MORE (survey):	Study on mobility patterns and career paths of EU researchers (April 2010),
OECD:	Organisation for Economic Co-operation and Development,
PCT:	The Patent Cooperation Treaty (PCT): an international patent law treaty, concluded in 1970,
UNESCO:	United Nations Educational, Scientific and Cultural Organization.

European Commission

EUR 25278 EN – Joint Research Centre – Institute for the Protection and Security of the Citizen
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EUR – Scientific and Technical Research series – ISSN 1831-9424 (online), ISSN 1018-5593 (print)
ISBN 978-92-79-22539-0
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Abstract
This report is the deliverable of the first work package (WP1) of the feasibility study entitled: 'ERA monitoring: Composite Indicators measuring the progress in the construction and integration of a European Research Area', financed by DG RTD. For this deliverable we developed a composite indicator to measure progress in the construction and integration of a European Research Area (ERA). The indicators required for this study and the theoretical framework have been drawn and adapted using the headline indicators proposed by the expert group report* on 'ERA indicators and monitoring' 2009 EUR 24171 EN. The report combines economic and statistical expertise and presents a comprehensive and flexible framework for an evidence-based monitoring of progress towards the European Research Area.

* The full report is available at: http://ec.europa.eu/research/era/pdf/era_indicators&monitoring.pdf

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